QUANTITATIVE ANALYSIS ON SCHEDULE, COST, AND CONTINGENCY: PERFORMANCE IMPLICATIONS OF INNOVATIVE CONTRACTING STRATEGIES

A Dissertation

by

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DOCTOR OF PHILOSOPHY

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ABSTRACT

Current plans to invest over $1.7 trillion on U.S. infrastructure will result in rehabilitation of one-fifth of the U.S. highway systems over the next ten years. Consequently, alternative project delivery and contracting strategies are seen as major interventions to address increasing pressure on project acceleration for minimizing public inconvenience due to extensive rehabilitation. Critics, however, highlight several impediments to project acceleration. First, the impact of project changes on project schedule and cost performance in terms of their occurrence timing is unknown. Second, the effectiveness of alternative contracting strategies on the aspect of project performance has not been fully evaluated. Lastly, the way project contingency plans are executed by state transportation agencies is ad-hoc, and has led to many misapplications that fail to mirror project risks into project planning and budgeting.

To circumvent these challenges, this study aimed to develop models for quantifying the effects of alternative delivery method (design-build) and contracting strategies (A+B, no excuse bonus, incentive/disincentive, and lump sum) on project performance. Particular emphases were given to (1) quantification of change order occurrence timing impacts on project performance under the design-build delivery method; (2) development of performance models with consideration of the simultaneity in schedule and cost under alternative contracting strategies; and (3) establishment of a comprehensive contingency adjustment framework that considers the performance impacts of alternative contracting strategies. The research objectives were accomplished by analyzing the large real-world dataset consisted of 1,103 rehabilitation, reconstruction, and resurfacing (3R) projects that were completed between 2002 and 2011 in Florida.

For the first objective, the results from the t-test and multiple linear regression indicated that design-build was more effective in restraining schedule and cost growths than the traditional design-bid-build. With respect to the occurrence timing of change order, it influenced significantly on schedule but negligibly on cost of the project. Contrary to the previous findings, the later occurrence of change order caused less schedule delays. The second objective was obtained by conducting the three-stage least squares, which can reflect the simultaneity in schedule and cost. The analysis results provided significant evidences of not only the simultaneity existence between schedule and cost but also accuracy and efficiency improvements in model estimation. In regard to the performance impacts of alternative contracting strategies, A+B (cost-plus-time bidding) was the most undesirable on aspects of both schedule and cost. Meanwhile, no excuse bonus and incentive/disincentive were effective in constraining schedule growths. Although lump sum is considered to have low project risks, it showed high degree of cost overruns. Finally, this study developed a comprehensive contingency adjustment framework based on sequential impacts of factors on needs for contingency adjustment. The framework using the path analysis implied that projects with long duration, owner's high initial estimate, lump sum contracting strategy, and a major contractor may need more contingency, while no excuse bonus contracting strategy and economic environments under recession may alleviate required contingency allocation.

This study provides the quantitative insights into the performance impacts of alternative project delivery method and contracting strategies, and the first holistic view to anticipate project factors' sequential impacts on contingency adjustment, which are applicable in project planning and budgeting.

DEDICATION

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1. INTRODUCTION

1.1. Background and Significance

Transportation infrastructure plays a pivotal role in societal welfare and national economy. However, the current U.S. highway systems are significantly obsolete and damaged because most of them were built between the 1950s and 1980s and already exceeded their 20-25-year life span (Choi et al. 2015; Choi and Kwak 2012; Choi et al. 2011; Choi 2010; Choi et al. 2013; Napolitan and Zegras 2008). According to the U.S. Department of Transportation (2015), 65 percent of major roads in the U.S. are in less than good condition and 24 percent of bridges need significant repair. However, the rehabilitation of these highly impaired road systems is a daunting task since it requires prohibitive costs: The American Society of Civil Engineering (ASCE) (2017) estimated future investment needs of $836 billion in total, which include $420 billion in the renewal of existing roadways and $123 billion in bridge repair.

In addition, the capacity of the current roadways also fails to meet drastically increasing traffic demands (Bae et al. 2017; Choi 2010; Lee et al. 2008; Napolitan and Zegras 2008). Vehicle miles traveled (VMT) drastically increased by 500 percent, from 600 billion to 3 trillion VMT, over the fifty years since the late 1950s, yet the addition of new roadways increased only by 15 percent during the same period (American Association of State Highway and Transportation Officials (AASHTO) 2007). The ASCE (2017) declared that 40 percent of urban highways were congested and the corresponding traffic delays cost $160 billion in wasted time and fuel in 2014 alone. These infrastructure conditions threatening public convenience and national economy have recently spurred the federal government to map out a plan that invests $1.7 trillion on improving the U.S. infrastructure (Fortune 2017; Reuters 2018).

Besides the rehabilitation of the deteriorated transportation infrastructure, accelerating project delivery and relieving traffic congestion during construction have also become significant challenges in transportation improvement projects (Federal Highway Administration (FHWA) 2014). This is because repairing the transportation systems can also induce traffic delays, consequent public inconvenience, and economic losses (Choi and Bae 2015; Choi et al. 2016; Choi et al. 2013; Choi et al. 2013). The FHWA (2017) estimated that in 2014, delays due to road construction work zones accounted for 24 percent of highway congestion and 10 percent of the overall congestion, causing fuel loss of 310 million gallons. Furthermore, there were 669 fatalities from crashes in road construction work zones in the same period, accounting for 2 percent of all national roadway fatalities (FHWA 2017). To circumvent these challenges, state transportation agencies (STAs) have adopted alternative approaches for early project completion to (1) reduce project delivery duration, (2) minimize inconvenience to road users and surrounding communities, and (3) restrain unfavorable economic impacts of road construction work zones.

STAs recognized that the traditional project delivery methods and the conventional contracting strategy have limitations in fast-tracking project delivery with the completion of projects within budget and timeline. As a solution, many STAs have pursued alternative delivery methods and contracting strategies. Design-bid-build (DBB) has been the most commonly used traditional delivery method over the last five decades (Ibbs et al. 2003; Ling et al. 2004; Shrestha et al. 2011; Sindhu et al. 2017). Since it employs linear sequences of design, bid, and construction, it is highly likely to have slow project delivery speed (Ibbs et al. 2003; Touran et al.

2009; Tran and Molenaar 2013; Tran and Molenaar 2015). As an alternative project delivery method, a Design-Build (DB) approach has become the preference of many STAs. It is believed to fast-track the project delivery by overlapping design and construction phases, and to improve communication among participants by services from a single design and construction entity (Borowiec et al. 2015; Gould and Joyce 2009; Hale et al. 2009; Ibbs et al. 2003).

As an attempt to overcome the shortfalls of the conventional contracting strategy, the STAs have adopted alternative contracting strategies, including A+B (cost-plus-time bidding), incentive/disincentive (I/D), no excuse bonus (Bonus), lump sum, lane rental, warranty clauses, and liquidated savings (Choi and Lee 2008). The Florida Department of Transportation (FDOT) defines these alternative contracting strategies as the followings (Ellis et al. 2007). In an A+B contracting, bidding consists of both prices and duration required to complete project and the contract is then awarded to the lowest A+B bidder. An I/D strategy encourages fast-tracking on a daily basis by providing incentive payments to the contractor for early completion and deducting disincentive amounts for late completion. No excuse bonus is a contracting strategy that awards monetary bonus when the contractor completes the project by a specified milestone date, a completion date, or both regardless of weather or unforeseen conditions. In a lump sum setting, the contractor tenders a single lump sum price instead of bid item prices.

Although the use of alternative delivery method and contracting strategies has been increasing since the 1990s, the selection of the exact approach is frequently made on an ad hoc basis with little quantitative insight on its possible consequent impacts on project performance (Tran and Molenaar 2015). Accordingly, improved quantitative understandings about the effectiveness of alternative approaches would significantly assist STAs to make better decisions associated with delivery and contracting approach selection. Therefore, this research developed models to estimate performance impacts of the alternative delivery method (DB) and contracting strategies (e.g., A+B, no excuse bonus, I/D, and lump sum). As a means to measure such effectiveness, this study mainly examined the impacts of change orders on project schedule and cost, which are a commonly used parameter in performance evaluation of the project.

However, construction projects are inherently uncertain and involve the high level of risks. As a result, schedule delays and cost overruns are prevalent and inevitable. Owners allocate additional costs over project budget to absorb such fluctuations in project schedule and cost: that is, contingency. Of many definitions of contingency, according to the Association for the Advancement of Cost Engineering (2017), contingency is defined as: "An amount added to an estimate to allow for items, conditions, or events for which the state, occurrence, or effect is uncertain and that experience shows will likely results, in aggregate, in additional costs. Typically estimate using statistical analysis or judgment based on past asset or project experience." Although contingency is intended to cope with project risks and corresponding cost changes, current contingency practice is neither accurate nor effective because STAs usually apply the traditional fixed rate over the project's original contract amount frequently without consideration of project characteristics and consequent project risks. For instance, the FDOT (2017) applies the contingency policy of the fixed rate and amounts regardless of project attributes and risks. Consequently, their contingency policy has limitations in addressing actual cost variances of the project. To overcome the current contingency estimation issue, the improvement of contingency calculation methods has been of interest among practitioners and researchers. However, there still need further research efforts to advance contingency estimating.

1.2. Problem Statements

When improving existing highway infrastructure systems, employing more efficient and effective project delivery methods and contracting strategies plays pivotal roles in achieving successful project completions (Goodrum et al. 2005; Ibbs et al. 2003; Molenaar and Yakowenko 2007; Touran et al. 2009; Tran and Molenaar 2015). Therefore, improved understandings about alternative approaches will serve as essential baselines for better selection of delivery and contracting methods at given project conditions and goals. Acknowledging this importance, many researchers have made concerted efforts to investigate and quantify the effects of alternative approaches on aspects of project performance and change order impacts. A review of previous studies, however, revealed a number of limitations as follows:

First, despite the growing use of alternative approaches, the research results regarding their effectiveness are incongruent. Although most past studies on project delivery methods concluded that DB outperforms the traditional DBB method, there exists conflicting findings. These conflicting results also exist in the research area of alternative contracting strategies. Moreover, it should be noted that most previous studies have focused largely on A+B and I/D provisions, while putting less or no emphasis on no excuse bonus, lump sum, and other alternative contracting strategies.

Second, because changes are inevitable in any construction projects, numerous researchers have investigated the unfavorable impacts of change orders. No study, however, has examined how the timing of change order occurrence influences on project performance. Depending on the occurrence timing of a change order, its impacts on project performance may vary. For example, it is commonly believed that a change order in the late stage of the project delivery may cause more negative impacts on performance than in the early stage. Moreover, change order frequency has not been included in the project performance assessment. Change order frequency itself can be a significant factor to project performance because it can represent the uncertainties and risks of the project. However, previous studies have focused mostly on uncovering reasons of change order frequency and measuring the level of frequency.

Third, a change order can cause solely schedule or cost variances, or lead to both schedule delays and cost overruns, simultaneously. Some previous studies have pointed out that schedule and cost aspects of the project are cross-correlated (Anastasopoulos et al. 2010; Bhargava et al. 2010; Kerzner 2017; Rajan et al. 2013; Shenhar and Dvir 2007). However, most of past studies usually employed separate equational models for the impact quantification. Therefore, additional research is needed to take into account the interdependent relationship between schedule and cost.

Fourth, many studies have analyzed relatively small quantity of construction data. Moreover, in many cases, the analysis has been performed without considering important confounding factors such as project work types. This might have caused biased analysis results. This kind of problem can be exemplified with the analysis without consideration of project types. New construction projects may have higher complexity and risks than renewal of the existing facilities. If the classification of project types (e.g., new versus renewal projects) are not considered in the analysis, it is not likely to fully reflect indigenous aspects of each project type. Therefore, it would be helpful to conduct the analysis with a large sample size and considering such confounding factors.

Lastly, although there have been numerous attempts to advance contingency estimation methods, there still exist gaps in the existing practice and literature. In particular, no study has developed a comprehensive contingency estimation framework that includes sequential impacts of factors through the lifecycle of the project under contracting strategies. Constriction activities can be categorized by their construction phases, such as planning, bidding and contract, construction, and completion. Each activity may be influenced by precedent activities or have impact on activities in the following phases. For instance, if an alternative contracting strategy is provided, bidding competition and pattern of contractors would be affected. Consequently, the project's original amount would be influenced, and the aspects of change orders and consequent project performance would be also affected. Therefore, consideration on these sequential impacts of factors may be beneficial in the investigation of factor impacts on project performance. In addition, in the intended research area, new innovative contingency methods have been introduced and adopted, including Monte Carlo simulation, fuzzy set techniques, and artificial neural network (ANN) methods. Although they have been successful in deriving accurate and effective contingency allocation, the implementation of such methods usually requires significant cost and time to conduct (Bakhshi and Touran 2009; Bakhshi and Touran 2014; Smith and Bohn 1999). Therefore, some of them would not be appropriate unless the project is large in scale and complicated. Moreover, some methods such as ANNs can barely represent the relationships among factors because they are largely s black-box method. Therefore, a comprehensive but point-and-shoot contingency estimation framework needs to be developed to better assist STAs, which is applicable to most of projects.

To address the aforementioned research gaps and to improve STAs' understandings about the effectiveness of alternative approaches, there is a pressing need to conduct additional research that focuses on: (1) investigating the effectiveness of alternative delivery method and contracting strategies, (2) developing models that quantify the effects of alternative approaches,

(3) assessing the impacts of change order occurrence timing and frequency on project performance, (4) developing models that reflect the simultaneity in project schedule and cost, (5) performing the analysis using real world construction data with a large sample and including consideration of project work types, and (6) creating a comprehensive but intuitive contingency calculation framework that reflects sequential impacts of factors through the construction phases.

1.3. Research Objectives

The primary goal of the current study is to develop models that quantify the impacts of alternative delivery method and contracting strategies on project schedule and cost. Particularly, based on the problem statements stated earlier, this research included the following three objectives and several sub-objectives:

Objective 1: Investigate the impacts of change order magnitude and change order occurrence timing on project schedule and cost under a DB setting in roadway rehabilitation projects;

- 1-1: Compare project schedule and cost performance of the DB method with the conventional DBB approach;
- 1-2: Examine the aspects of change order magnitude and occurrence timing between DB and DBB; and
- 1-3: Develop models that can quantify the likely impacts of change order magnitude and occurrence timing on project performance in DB highway renewal projects

Objective 2: Develop quantitative performance models for the effectiveness of contracting strategies with consideration of the simultaneous relationships between project schedule and cost under alternative contracting strategies in roadway renewal projects;

- 2-1: Determine whether the use of alternative contracting strategies influenced on project schedule and cost by comparing with projects with alternative contracting strategies with those of the conventional contracting strategy;
- 2-2: Examine the degree of change order magnitude and frequency among contracting strategies; and
- 2-3: Establish quantitative models that can represent not only the performance impacts of alternative contracting strategies but also the cross-correlated impacts of project schedule and cost.

Objective 3: Create a comprehensive contingency estimation framework that can reflect sequential impacts of factors through the lifecycle of the project with the consideration of the effectiveness of contracting strategies in roadway renewal projects;

- 3-1: Examine sequential relationships among factors through project lifecycle from planning to completion stages
- 3-2: Investigate the impacts of alternative contracting strategies on contingency adjustment needs as well as factors in succeeding stages
- 3-3: Devise a contingency adjustment framework that can visually represent the lifecycle features of the project factors

The first objective was established based on the idea that DB may have a tendency of earlier change order occurrence since it overlaps with procurement processes and starts the construction phase before the design completion. Therefore, it was expected to more explicitly represent the timing impacts of change order occurrence on project performance. The second objective did not take the timing impact of individual change order occurrence into account since its primary purpose was to reflect the simultaneity in project schedule and cost under alternative contracting strategies. The third objective mainly focused on cost contingency. Despite the possible existence of the simultaneity in schedule and cost, the study did not include schedule contingency in the third phase.

1.4. Research Methods

To accomplish the aforementioned research objectives, the current research employed multiple quantitative research methods of post-hoc tests, t-test, Kruskal-Wallis test with Dunn's test, multiple linear regression, three-stage least squares, and path analysis drawing on a large-quantity dataset obtained from the Florida Department of Transportation (FDOT). The following steps were undertaken in this research: (1) data classification, (2) descriptive and trend analysis, (3) comparative and post-hoc analysis, (4) variable identification, (5) statistical assumption check, (6) development of models, (7) interpretation and discussion of analysis results and findings.

1.4.1. Research Area

There has been a shift in the roadway projects from new construction to rehabilitation due to the significantly aged and damaged roadway systems (Choi 2017; Choi and Kwak 2012; Choi et al. 2011; Herbsman et al. 1995). The initial dataset obtained from the FDOT comprised of 3,007 roadway projects completed over the 10-year period between 2002 and 2011 in Florida. The initial data classification procedure also affirmed that rehabilitation, reconstruction, and resurfacing (3R) projects were the dominant project work type: 32.7 and 36.5 percent in the project number and dollar amounts, respectively, as shown in Figure 3.3. To reflect this trend change and avoid biased analysis results, the study mainly focused on the 3R projects.

1.4.2. Research Methods

The research objectives were accomplished using quantitative analysis techniques. For the first research objective, the impact quantification of change order magnitude and occurrence timing in DB roadway renewal projects, a multiple linear regression approach was used. The second objective, the investigation of the simultaneity in schedule and cost performance under alternative contracting strategies, employed systemic equations that can take the existence of the simultaneity into account. In the third objective, path analysis was applied as a technique to develop a comprehensive contingency adjustment framework. As a basis for developing these three main models, this research also conducted a series of comparative and post-hoc tests: e.g., t-test, Kruskal-Wallis test, goodness of fit test, and other necessary statistical techniques.

Phase I: Impacts of Change Order Occurrence Timing on Performance in DB Projects

For quantifying the impacts of change order magnitude and occurrence timing on project cost and schedule in DB highway renewal projects, a multiple linear regression analysis was used. The research at this time establishes the following two respective equations for predicting the likely impacts of change order magnitude, occurrence timing and frequency on cost and schedule performance of the project;

$$SPR = \alpha_s + \beta_s \cdot X_s + \gamma_s \cdot TSCR + \delta_s \cdot TCCR + \lambda_s \cdot SCR + \sigma_s \cdot CCR + \theta_s \cdot I + \varepsilon_s \qquad (1)$$

$$CPR = \alpha_c + \beta_c \cdot X_c + \gamma_c \cdot TSCR + \delta_c \cdot TCCR + \lambda_c \cdot SCR + \sigma_c \cdot CCR + \theta_c \cdot I + \varepsilon_c \quad (2)$$

where, SPR and CPR = schedule and cost performance ratios, respectively; X_s and X_c = vectors of variables affecting project schedule and cost performance, respectively; TSCR and TCCR = total days and amounts change rate by total change orders of the project, respectively; SCR and CCR = days and amounts change rate by individual change order, respectively; Timing = occurrence timing of each change order; and I = indicator variable for project delivery methods (1 if DB, 0 otherwise).

Phase II: Simultaneity in Project Schedule and Cost under Alternative Contracting Strategies

Change orders and other factors may be influential to both project schedule and cost, simultaneously. Therefore, this interdependency between schedule and cost should be taken into account in models, which quantify the probable effects of change orders and other factors on performance under alternative contracting strategies. To this end, this research initially set up the following equation system;

$$SPR = \alpha_s + \beta_s \cdot X_s + \gamma_s \cdot TSCR + \delta_s \cdot TCCR + \theta_s \cdot I_i + \varepsilon_s \quad (3)$$

$$CPR = \alpha_c + \beta_c \cdot X_c + \gamma_c \cdot TSCR + \delta_c \cdot TCCR + \theta_c \cdot I_i + \varepsilon_c \quad (4)$$

where, SPR and CPR = schedule and cost performance ratios, respectively; X_s and X_c = vectors of variables affecting project schedule and cost performance, respectively; TSCR and TCCR = the ratio of total change order days and amounts over original contract days and amounts, respectively; I_i = indicator variables for contracting strategies; and εs = error terms.

Although the above two equations do not include direct interactions, they would have correlated error terms since cost overruns and schedule delays may be attributed to the same or similar project risks, also meaning that the same risks or changes may influence both cost overruns and schedule delays of the project. Efficient parameter estimates of this equation system can be accomplished by considering the synchronical correlation of error terms. Therefore, this research applies the three-stage least squares (3SLS) method to account for the possible correlation between two dependent variables and to seek the efficiency in model estimation.

Phase III: Integrated Contingency Adjustment Framework

Based on the results in the phase II, the study developed a comprehensive contingency adjustment framework that implies factors' impacts on contingency adjustment needs over the owner's fixed rate contingency. Construction activities can be categorized into four stages in accordance with their sequences: namely, planning, bidding and contract, construction, and completion. In the completion phase, actual schedule and cost are determined. Subsequently, actual required contingency can be also confirmed in that stage. Based on this concept, the study initially set up the following path model, as shown in Figure 1.1.

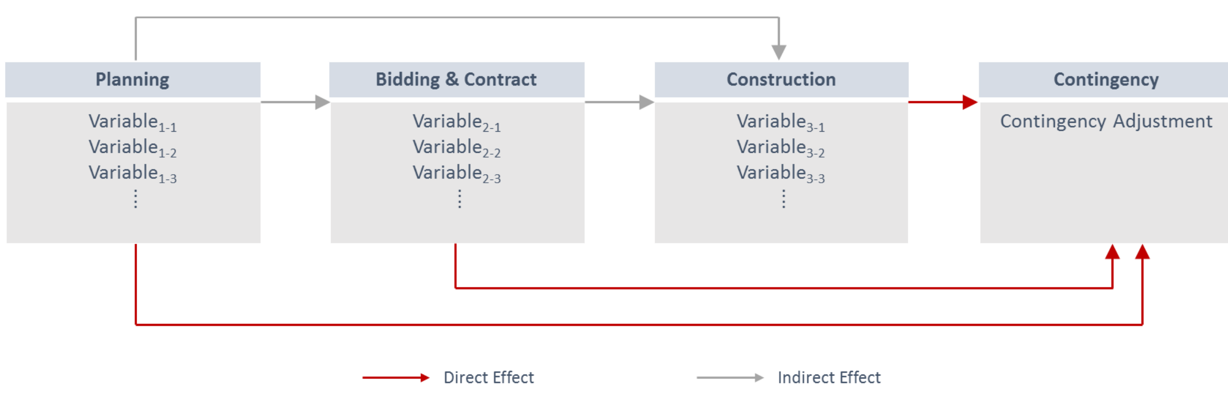


Figure 1.1. Concept of Path Model for Contingency Adjustment

An appropriate analytical means to mirror pathwise causal relationships is path analysis, which can be consisted of two or more causal-effect regression models (Garson 2013). It can also provide an intuitive path diagram that represents complex causal and/or interrelated relationships of factors (Garson 2013; Hair et al. 2006; Kim et al. 2009; Yuan et al. 2018). Because this phase specifically aimed at suggesting a comprehensive but point-and-shoot framework, path analysis was used.

1.5. Research Assumptions and Limitations

The analysis in this research was conducted on a basis of the specific region, the state of Florida. The FDOT has 7 regional sectors and may have intrinsic practices differing among sectors and from other STAs. Hence, there may be some factors that influence on schedule and cost performance of the project, such as geographic and environmental conditions, procurement and management practices, temporal changes in the construction trend, and so forth. Nevertheless, considering the research intentions, this research assumed that the aforementioned aspects acted homogenously through all the projects and regional sectors. Additionally, the research presumed that the selection of project delivery methods and contracting strategies was made rationally by the agency. Although all the projects in the data were procured by the single agency, they were conducted in different sites and at different times. Therefore, the projects in the data are assumed to be independent.

In these regards, this research has some limitations. First, the impacts of unobserved factors were not considered. Second, as the research mainly focused on roadway rehabilitation projects, other project types (i.e., new construction, bridge repair and construction, capacity added, and others) are beyond the scope of this study. Finally, as alternative delivery method and alternative contracting strategies are usually applied to large-scale projects, the research excluded projects that have amounts and duration above or below specific bounds, to derive unbiased results. Therefore, the research results would not represent all rehabilitation projects.

1.6. Research Significance

The main contribution of this study is expected to be quantifying the likely effects of delivery methods and contracting strategies on project schedule and cost performance and developing a comprehensive contingency estimation framework. More specifically, it will develop schedule and cost models and integrated contingency adjustment framework to provide quantitative insights toward the effectiveness of an alternative project delivery method and alternative contracting strategies, and the impacts of other confounding factors. The estimated project variations derived from the models will, in turn, help practitioners in STAs to make a better informed decision in delivery method and contracting strategy selection and contingency allocation. Furthermore, the results and findings will serve as a basis for remedial measures to minimize the possible impacts on project schedule and cost growths, which are applicable during project planning, procurement, and construction phases.

1.7. Dissertation Organization

The primary objective of this study is to develop models that can quantify the effectiveness of alternative project delivery method and contracting strategies. Chapter 1 briefly introduced the necessity of the study, the identified research problems and research objectives, and the corresponding research methods to accomplish the goals. In Chapter 2, the literature review pertinent to the themes of the study was discussed. The data and variables used in the study were explained with descriptive analysis results in Chapter 3. The study particularly aimed at achieving the following three research objectives: (1) quantification of change order occurrence timing impacts under two different project delivery methods (DB versus DBB); (2) development of performance models with the simultaneity in project schedule and cost under alternative contracting strategies; (3) establishment of a comprehensive but point-and-shoot contingency estimation framework that takes account of the effectiveness of alternative contracting strategies. Those three objectives and corresponding research questions were covered in Chapter 4, 5, and 6, respectively. The last chapter summarized and concluded the overall research results and findings while discussing the contributions and significances of the study and the implications for future research.

2. LITERATURE REVIEW

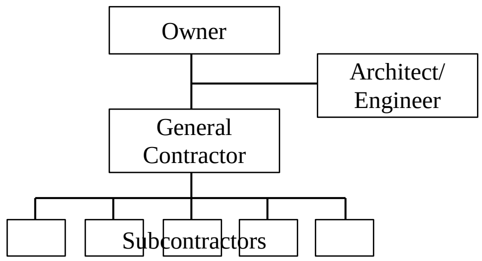
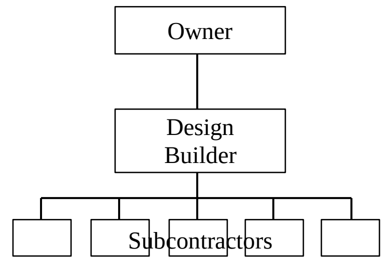
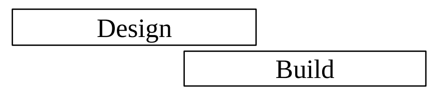
As changes and consequent schedule delays and cost overruns are significant issues across the architecture, engineering, and construction (AEC) industry, there have been concerted efforts to investigate the reasons of changes and quantify their possible impacts on project cost and schedule. Moreover, alternative project delivery method and alternative contracting strategies, which have emerged to overcome the limitations of traditional approaches in fast-tracking the project delivery within planned budget and duration, have been at the center of research interests. A review of literature, however, shows significant gaps in transportation infrastructure research as follows: (1) incongruent results about the effectiveness of alternative approaches; (2) no quantification of change order occurrence timing impacts; (3) lack of study on the simultaneity in project schedule and cost under alternative contracting strategies; (4) lack of study analyzing a large-quantity dataset considering diverse project work types; (5) absence of a comprehensive contingency estimation framework that takes into account the effectiveness of alternative contracting strategies. This literature review is divided into six sections: project delivery methods, alternative contracting strategies, change order and their impacts, factors affecting project performance, simultaneity in project schedule and cost, and contingency practice and research.

2.1. Project Delivery Methods: Design-Bid-Build (DBB) and Design-Build (DB)

DBB has been the most widely used traditional delivery method for public capital projects over the past five decades (Ibbs et al. 2003; Ling et al. 2004; Shrestha et al. 2011). Under a DBB setting, design and construction occur in a sequence of solicitation steps for each phase (Molenaar and Yakowenko 2007). Since bidding starts after the completion of design, and the owner enters into two separate contracts with an architecture/engineer (A/E) firm and construction company, it is likely to result in poor project quality due to the lack of communication between those two separate entities and slow project delivery speed by linear sequences of phases (Ibbs et al. 2003; Touran et al. 2009; Tran and Molenaar 2013; Tran and Molenaar 2015).

To overcome the shortfalls of the traditional DBB approach, numerous STAs have increasingly used DB as an alternative project delivery method since the 1990s (Molenaar and Yakowenko 2007; Shrestha et al. 2011; Tran and Molenaar 2015). In contrast to DBB, the owner procures both design and construction services from a single entity under a DB delivery setting, benefiting from improved communication among stakeholders (Borowiec et al. 2015; Gould and Joyce 2009; Hale et al. 2009; Ibbs et al. 2003). Also, as depicted in Table 2.1, since DB overlaps two delivery stages of design and construction, projects with DB can reduce the duration of project delivery. Due to the decisive advantages, the number of states legislatively authorizing the use of DB in public projects increased from 3 states in 1993 to 42 states and the District of Columbia in 2016 and most DB-related bills focused on the transportation sector due to increased infrastructure priorities nationwide (Design-Build Institute of America 2017).

Table 2.1. Structure and Procedure of Design-Bid-Build and Design-Build

	Design-Bid-Build (DBB)	Design-Build (DB)
Structure		
Procurement Procedure		

From the perspective of the DB effectiveness, past studies on DB in the overall AEC industry, in general, found that DB outperformed DBB on aspects of project cost and schedule (Hale et al. 2009; Konchar and Sanvido 1998; Molenaar and Songer 1998; Songer et al. 1996). However, the findings in the highway projects have been incongruent. Ellis et al. (1991) concluded that DB led to 2 percent less cost overruns than DBB in several highway projects completed in Florida. A report published by the FHWA (2006) indicated that DB delivery reduced the overall project duration by 14 percent and the total cost by 3 percent on average while maintaining the same level of quality as compared to DBB delivery. Shrestha et al. (2007) analyzed 15 highway projects and found that DB decreased project cost by 6 percent while DBB showed 4 percent overruns. Conversely, subsequent research by Shrestha et al. (2011) showed 8 percent cost overrun and 21 percent schedule delay in DB projects as opposed to 6 percent and 5 percent in DBB. However, their findings were not statistically significant. Recently, Minchin et al. (2013) studied 51 highway and bridge projects completed between 2002 and 2011 in Florida and reported 40 percent cost overruns in DB and 20 percent in DBB. Yet, schedule delays in DB and DBB were 20 percent and 23 percent, respectively. Moreover, Creedy et al. (2010) founded that there was no strong correlation between project delivery methods and cost growths.

2.2. Alternative Contracting Strategies

Akin to project delivery methods, alternative contracting strategies have emerged to tackle the limitations of the traditional contracting approach in fast-tracking the project delivery. As shown in Table 2.2, alternative contracting strategies include the followings: A+B, I/D, no excuse bonus, lump sum, lane rental, liquidated savings, and warranty clauses. Of these, A+B, I/D, no excuse bonus, and lump sum are the preference of many STAs and most previous studies have focused largely on A+B and I/D strategies.

Table 2.2. Types of Alternative Contracting Strategies in Roadway Construction Projects

Contracting	Feature	Best Suited
A+B	· Lowest combined bid for cost plus time	Urban and bridge project with high traffic volume
Incentive/ Disincentive	· Incentive for early completion and penalty for late completion	Urban and bridge project with high traffic volume
No Excuse Bonus	· Bonus for early completion within a specified time · No consideration of any issues and conditions including weather and accident	Projects having importance in a specified timeframe
Lump Sum	· Lump sum price bidding instead of bid item price to reduce quantity overruns	Projects with well-defined scope and low uncertainties
Lane Rental	· Cost + (lane closure days × road user cost)	Milling, resurfacing, bridge widening
Liquidated Savings	· Granting reward for early completion based on savings in construction engineering and inspection (CEI) and administration cost · Consideration of unforeseen events and conditions	Milling, resurfacing
Warranty Clauses	· Guarantee of integrity of product and contractor's responsibility of product defects · Incentive based on life-cycle cost	Bridge painting, striping, asphalt pavement contracts

The A+B strategy is a cost-plus-time bidding that awards the lowest bidder based on a monetary combination of the bid amounts (“A” portion) and the time (“B” portion) for project completion, by multiplying the time by the estimated daily road user cost (El-Rayes 2001; Michigan Department of Transportation 2015; Shr et al. 2004; Shr and Chen 2003). This approach assists STAs to select a contractor who can shorten project duration, consequently minimizing the public inconvenience caused by road construction (Washington Department of Transportation 2016).

The I/D technique provides the contractor monetary incentives for early completion and penalties for late completion to encourage accelerated construction (Choi and Kwak 2012; Choi 2010; Ellis and Pyeon 2005; Goodrum et al. 2005; Jiang et al. 2010; Shr and Chen 2006; Shr et al. 2004). Under this strategy, STAs can reduce construction duration and contractors can earn more profits with incentive fees provided by the shorten duration (Choi 2010). This approach is, in general, applied to projects in heavily trafficked roads where primary goals are to achieve the early project completion and restrain public inconvenience (Christiansen 1987; Fick 2010; Ibarra et al. 2002; Jaraiedi et al. 1995; Rister and Wang 2004; Shr and Chen 2004).

Similarly, the no excuse bonus method, which is also known as no excuse incentive, can reduce construction time by tying an incentive to the completion of the project and/or specific construction milestone activities by a set date (Ellis Jr et al. 2007; Florida Department of Transportation 2017; Michigan Department of Transportation 2015). However, since incentive amounts are substantial, there are no excuses for any issues or unforeseen conditions that may occur during the construction (Ellis Jr et al. 2007; Federal Highway Administration (FHWA) 2016; Michigan Department of Transportation 2015). This technique is applicable to projects that must be open to meet a critical date (Federal Highway Administration (FHWA) 2016).

The lump sum bidding does not pursue the early completion of the project. Instead, it is designed to reduce possible quantity overruns and the contract administration related costs (Ellis et al. 2007; Federal Highway Administration (FHWA) 2016). Bidders, in this setting, tender a single lump sum price instead of bid item prices, thereby allowing them to spend more time on inspection and less on paperwork (Ellis et al. 2007). This approach is used to projects with well-defined project scope and low project uncertainties (Florida Department of Transportation 2001).

Alternative contracting techniques, in general, can be utilized to minimize project implementation delays, accelerate construction, and shorten construction duration, consequently restraining work zone impacts of road construction projects (Choi and Kwak 2012; Choi et al. 2011; Choi 2010; Choi et al. 2016; Sankar et al. 2006). However, their effectiveness is inconsistent across the past studies and little is known about their change order impacts on project cost and schedule (Choi and Kwak 2012; Choi et al. 2011; Choi et al. 2016; Herbsman and Glagola 1998).

A number of studies have reported the promising results that alternative contracting strategies produced intended outcomes (Anderson and Russell 2001; Arditi et al. 1997; Ellis Jr et al. 2007; Jaraiedi et al. 1995; Scott et al. 2006). Anderson and Russell (2001) concluded that the provision of warranty clauses improved the quality of the facility after project completion. Scott et al. (2006) evaluated 77 A+B projects in 19 states and found that they were effective in schedule compression. Jaraiedi et al. (1995) and Arditi et al. (1997) reported that 93 percent of I/D projects were completed on time or ahead of schedule and drastically reduced construction duration by up to 50 percent. The FDOT’s summary on alternative contracting executive in 2007 reported that the alternative contracting strategies were more beneficial than the conventional approach in both project time and cost: namely, A+B, A+B with bonus, and Bonus contracting strategies were the most efficient in time savings (Ellis et al. 2007).

However, there also have been contrary research results that the effectiveness of some alternative contracting strategies were ineffective or debatable when compared to the conventional contracting method or other strategies (Choi and Kwak 2012; Choi et al. 2011; Choi et al. 2016; Herbsman et al. 1995; Shen et al. 1999; Shr et al. 2004; Shr and Chen 2003; Shr and Chen 2004). For the effectiveness of A+B, Christiansen (1987) pointed out that A+B projects can be less effective as bidders may estimate inaccurate time or purposefully underestimate to win the bid. Choi et al. (2011) also found that A+B projects with I/D experienced more schedule delays. There also have been a number of studies that have raised questions about the effectiveness of I/D. The inaccurate project duration estimates of STAs could serve as a poor basis for incentive award, meaning that STAs' duration overestimation could allow contractors to easily receive incentives without extra commitments (Choi et al. 2016; Herbsman et al. 1995; Rister and Wang 2004; Shr and Chen 2004). Recently, Choi et al. (2016) analyzed the effectiveness of pure A+B and I/D combined with A+B on aspects of the impacts of change orders using 1,372 highway projects in California and concluded that both approaches led to more schedule and cost changes than the conventional method.

2.3. Change Order and Its Impacts on Performance

A change order is an additional contractual document to accommodate any additional work beyond the original contract, which includes a modification of the original scope, cost, and/or schedule of the project (Anastasopoulos et al. 2010; Bhargava et al. 2010; Chen and Hsu 2007;

Choi et al. 2016; Hanna et al. 1999). Change orders can stem from many factors such as design errors, unforeseen site conditions, unrealistically low winning bid amounts, labor insufficiency, material and equipment related issues, political problems, disputes, and inclement weathers (Anastasopoulos et al. 2010; Rosenfeld 2013; Russell et al. 2014; Serag et al. 2010; Taylor et al. 2012) . Construction projects are inherently uncertain, so change orders are inevitable and ubiquitous across the AEC industry. Change orders are known to be a main culprit of cost overruns, schedule delays and the reduction in labor productivity (Assaf and Al-Hejji 2006; Chester and Hendrickson 2005; Fayek et al. 2003; Fayek and Oduba 2005; Moselhi et al. 2005; Wichern 2004).

Accordingly, there have been past studies quantifying the change order impacts on project performance. To point a few, Al-Momani (2000) investigated causes of delays and conducted a simple linear regression analysis to estimate possible schedule delays. Hanna et al. (2002) performed a logistic regression to predict the influence of the change order on labor productivity in electrical and mechanical projects. In 2004, Hanna and Gunduz (2004) developed a model that estimates labor efficiency loss due to change orders in small projects. Moselhi et al. (2005) developed a neural network model to measure the impacts of change orders on labor productivity based on 33 Canada and USA projects. Serag et al. (2010) quantified the percentage increase in cost caused by change orders using regression models drawing on 16 FDOT projects. Choi et al. (2016) conducted a two-stage analysis to compare the effectiveness of accelerated contract provisions such as A+B and I/D with A+B with that of the conventional approach and to develop numerical models that predict the likely impact of change orders under accelerated contract provisions.

Through a review of the change order related literature, this research has identified that relatively few studies have focused on the timing impact of change order occurrence and most of them have concentrated mainly on labor productivity. Overall results showed that later changes had more negative impacts on labor productivity. Ibbs and Allen (1995) analyzed 104 projects from 35 different companies to test whether later changes are implemented less efficiently than earlier ones. Yet, they were not able to statistically support the hypothesis. A subsequent study by Hanna et al. (1999) used 61 projects from 13 mechanical contractors and included a weighted timing factor for change order timing int the formula. They concluded that change orders occurring late have more impacts on labor productivity than those occurring early in mechanical construction. Similarly to Ibbs and Allen (1995), however, they could not quantify the effect of change order timing. Chick (1999) concluded that later changes tend to have more impacts due to the limited time, large amount of material, and construction and crew interruption. Moselhi et al. (2005) developed a neural network model based on the analysis of 33 work packages in Canada and U.S. Their model included the build-up and rundown of labor hours normally spent to perform the work. Although the inclusion of the change order timing variable improved the estimation accuracy, the explicit impacts of change order timing was not discussed due to the black-box nature of the developed neural network model. Ibbs (2005) studied the impact of change order timing on labor productivity by categorizing projects into threefold; early (25 percent of the projects that change order was considered fastest), normal (middle 50 percent), and late (slowest 25 percent). The regression analysis showed that earlier changes had less unfavorable impacts on labor productivity than later changes. Serag et al. (2010) analyzed 11 variables collected from 16 Florida roadway projects to examine their impacts on cost overruns due to change orders and concluded that late change order timing significantly increased the project costs.

In regard to change order frequency, previous studies have largely focused on uncovering factors that influence on the frequency of change order. Rowland (1981) examined the causes, causality, and change order effects of projects in Georgia and indicated that the project complexity increased change orders and consequent cost and time overruns. Hester et al. (1991) studied the forms of dispute including the magnitude and frequency of change orders in insulation works in Texas and concluded that the impacts of change order were significant in project cost. Bordat et al. (2004) focused on the bidding-related factors affecting change order frequency in highway construction projects in Indiana. They reported that the major factors of schedule and cost growths and change orders were contract amount, difference winning bid amounts and second bid amounts, and difference between winning bid amounts and owner’s estimate. Recently, Anastasopoulos et al. (2010) analyzed the influence of project type, contract type, project duration, and size on change order frequency by applying a count-data model with five year contract data of Indiana highway projects. Their findings implied that the projects with larger amounts and longer durations encountered fewer change orders.

2.4. Factors Affecting Project Performance

Considerable amounts of past studies have evaluated project cost and schedule with many factors affecting project performance. On the basis of those past studies, it has been identified that the major causes of cost overruns and schedule delays are associated with poor design and estimates, inadequate management, project type, size, duration, complexity, level of bidding competition, site circumstances, weather, and so on (Anastasopoulos et al. 2010; Anastasopoulos et al. 2010; Baccarini 2004; Baccarini 2006; Borowiec et al. 2015; Choi et al. 2004; Choi and Bae 2015; Choi et al. 2015; Choi and Lee 2016; Choi et al. 2015; Choi 2015; Choi et al. 2013; Choi et al. 2013; Flyvbjerg et al. 2002; Flyvbjerg et al. 2003; Flyvbjerg et al. 2004; Forcada et al. 2017; Gransberg and Shane 2010; Günhan and Arditi 2007).

Akinci and Fischer (1998) reported that risk factors associated with cost performance were the project design, construction, and project environment. Hinze et al. (1992) analyzed cost overruns in Washington State highway projects and concluded that the cost overruns increased by project size. Rowland (1981) concluded that cost overruns were derived from contract size, complexity, length of communication channels, and distortion of information associated with larger projects. Similarly, Jahren and Ashe (1990) found that larger projects had 1 to 11% more cost overrun rate than smaller projects and the winning amount less than the agency's estimate also caused higher cost overrun rate. Chang (2002) analyzed the reasons for cost and time growths in engineering design projects and reported important factors such as work scope increase, legislation or standards changes, and archeological discoveries. Gkritza and Labi (2008) concluded that larger and longer projects were more prone to cost overruns. Flyvbjerg et al. (2004) determined that cost growth was affected by the implementation phase length and project type. From the perspective of schedule delays, Chan and Kumaraswamy (1997) conducted a survey in Hong Kong and found the main reasons of delays to be poor site management, poor supervision, unexpected ground conditions, and owner-initiated changes. Al-Momani (2000) reported that the major causes of schedule delays were related to designers, weather, economic conditions, site conditions, and quantity increase. Shrestha et al. (2013) conducted an ANOVA test on 363 public works and found that large, long-duration projects had more schedule overruns than small, short-duration projects. In 2005, Williams (2005) developed regression and neural network models for predicting highway project costs using bidding information, such as ratios of second lowest bid, mean bid, and max bid to the low bid. Of those factors, low bid, and low bid and second lowest bid were only significant in his regression model and neural network model, respectively. However, the study conducted by Baccarini (2004) reported that there were no significant correlations between cost variances and bid-related factors, such as date of bid, number of bidders, and mean value of bids. Creedy et al. (2010) identified risk factors causing cost overruns and concluded that design and scope changes are the most contributing factors to cost growths.

2.5. Simultaneity in Project Schedule and Cost

Because schedule delays and cost overruns are prevalent across the AEC industry, there have been a considerable number of studies investigating causes of schedule delays and cost overruns, and quantifying their consequences on schedule and cost performance of the project. However, a majority of studies have been mainly rooted in the approach that schedule delays and cost overruns are separate events (Bhargava et al. 2010). Subsequently, most of the previous studies largely have employed individual models for project schedule and/or cost. Such an approach would be still meaningful in providing quantitative insights into factors' performance impacts. However, since project schedule and cost variances are affected by similar attributes, there may be interdependent, or simultaneous, relationships between project schedule and cost (Bhargava et al. 2010; Bordat et al. 2004; Chan and Kumaraswamy 1997; Chang 2002; Choi and Kwak 2012;

Flyvbjerg et al. 2003; Flyvbjerg et al. 2004; Jahren and Ashe 1990; Williams 2005; Zheng and Ng 2005).

Although simultaneity in multiple aspects is widely and commonly considered in model development across various research domains, it has rarely been applied in the research area of project performance, especially, in transportation infrastructure construction projects (Anastasopoulos et al. 2010; Bhargava et al. 2010; Lin 2005). The first attempt to take into account the simultaneity in schedule and cost of roadway projects was implemented by Bhargava et al. (2010). Based on cognizance of simultaneity existence in schedule and cost, they employed the ordinary least squares as well as the three-stage least squares (3SLS) methods to identify factors affecting schedule delays and cost overruns under different project work types (Bhargava et al. 2010). Their estimated models drew on 1,862 roadway projects and affirmed that simultaneity in schedule and cost exists and 3SLS is more effective and accurate than OLS. Subsequent research conducted by Anastasopoulos et al. (2010) also supported the effectiveness of 3SLS in estimation efficiency and accuracy. They developed a 3SLS based framework for the appropriate contract type selection in a highway maintenance and rehabilitation project by analyzing 487 highway contracts let between 1997 and 2007 across the globe (Anastasopoulos et al. 2010). Rajan et al. (2013) also demonstrated the significance and applicability of the 3SLS method in effective and accurate model estimation. They investigated performance impacts of public private partnership projects in India. Their 3SLS results helped to circumvent the simultaneity bias in schedule and cost and yielded statistically significant results.

2.6. Contingency Practice and Research

The issue of cost growths in the construction industry is prevalent and inevitable across the globe, due to the inherently uncertain nature of construction projects. This phenomenon is even more frequent and severe in the area of transportation infrastructure construction (Creedy et al. 2010; Molenaar 2005). To take an example, approximately 50 percent of large transportation projects in the U.S. experienced cost overruns (Sinnette 2004). For the severity of cost growths, Flyvbjerg et al. (2003) pointed out that transportation infrastructure projects in the U.S. had an average of 28 percent overruns over the past seven decades. However, in practice, contingency is determined on the basis of STAs' predetermined fixed rates and/or expert judgment (Bakhshi and Touran 2014). The contingency percent under the traditional approach ranges from 5 to 10 percent of the project original contract amount (Federal Highway Administration 2007). On a more serious note, consideration of project conditions and risks is often ignored under the traditional fixed rate method (Bakhshi and Touran 2014).

As a response to the inaccuracy and ineffectiveness in contingency practice, there have been a considerable amount of studies aiming at improving contingency estimation methods. As alternative contingency calculation approaches, probabilistic and modern mathematical methods have been introduced (Bakhshi and Touran 2014). Contrary to the traditional deterministic fixed rate approach, probabilistic methods reflect project uncertainties based on pertinent statistical distributions, thereby revealing the probabilistic nature of contingency estimating (Touran 2006). Probabilistic methods include program evaluation and review technique (PERT), parametric estimating, regression, analytical hierarchy process (AHP), and Monte Carlo simulation (Bakhshi and Touran 2009; Dey et al. 1994; Humphries 2009; Isidore and Back 2002; Kim and Ellis Jr

2006; Moselhi 1997; Moselhi and Dimitrov 1993; Roberds and McGrath 2006; Touran 1993; Touran and Bakhshi 2010; Yeo 1990). Recently, emerging modern mathematical techniques such as fuzzy techniques and artificial neural network have been also adopted in the research terrain of contingency estimating. Fuzzy techniques are based on a fuzzy set theory for modeling intrinsic vagueness in the human cognitive process (Chan et al. 2009). To this end, they have an advantage in capturing and assessing risks under the circumstances that no statistical data are available and, consequently, qualitative information such as expert opinions is important (Sachs and Tiong 2009). Pertinent past studies have supported that the use of fuzzy sets and logics is effective in the risk assessment and contingency estimation of construction projects (Bakhshi and Touran 2014; Chan et al. 2009; Choi et al. 2004; Paek et al. 1993; Sachs and Tiong 2009). Another modern mathematical method that has gained in popularity is an artificial neural network (ANN). ANN can provide predictive solutions through processes of learning from training samples and detecting hidden relationships among data, and it is very effective in modeling complex non-linear relationships (Kulkarni et al. 2017; Schmidhuber 2015; Sommer et al. 2015). Due to these distinctive advantages, there have been notable previous studies that employed ANN in risk assessment and contingency prediction (Baccarini 2006; Bakhshi and Touran 2014; Chen and Hartman 2000; Touran and Lopez 2006).

However, probabilistic and modern mathematical approaches have limitations. They, in large, require significant expense and time to conduct, and are likely not suitable unless the project is huge-scaled and complex (Bakhshi and Touran 2009; Bakhshi and Touran 2014; Smith and Bohn 1999). Moreover, ANN techniques are black-box methods in principle, so it is difficult to provide and explain the relationships between inputs and outputs (Kim et al. 2004; Kulkarni et al. 2017).

2.7. Chapter Summary

The previous literature provided noteworthy implications about current practice and research on the effects of alternative project delivery method and contracting strategies on project schedule and cost. Particularly, the literature review highlights needs for further research on (1) quantification of change order magnitude and occurrence timing impacts under DB and DBB project delivery methods; (2) development of performance models that consider the simultaneity in project schedule and cost under alternative contracting strategies; and (3) establishment of a comprehensive but point-and-shoot contingency estimation framework that takes the effectiveness of alternative contracting strategies into account.

3. DATA COLLECTION AND DESCRIPTIVE ANALYSIS

The study primarily aimed at developing models that can quantify the performance impacts of change order under alternative project delivery method and contracting strategies and devise a corresponding contingency adjustment framework. To this end, the study collected and analyzed data for 3,007 roadway construction projects completed between 2002 and 2011 in Florida. This chapter discussed the natures of the data, variables used in the analysis, and initial descriptive analysis results.

3.1. Research Data and Scope

The primary source of the data was the FDOT. The data are comprised of 3,007 roadway projects completed over the 10-year period between 2002 and 2011 in Florida, as illustrated in Figure 3.1. The dataset includes various project attributes such as project work types, project delivery methods, contracting strategies, original contract amounts and duration, actual amounts and duration, and detailed change order information and bidding and letting information, as shown in Figure 3.2. Therefore, the data classification process is essential to avoid biased analysis results. For example, new construction projects would involve higher uncertainties when compared to the rehabilitation of existing facilities. Through the initial classification, the distribution of project work types was firstly identified. As shown in Figure 3.3, of various project types, 3R projects had the highest proportion, accounting for 32.7 percent and 36.5 percent in number of projects and budget allotments, respectively. During the two decades, the trend of the transportation infrastructure improvement projects has shifted from new construction to rehabilitation to cope with the significantly aged and damaged roadway systems (Choi and Kwak 2012; Choi et al. 2011; Herbsman et al. 1995). The FDOT also proclaims that their primary mission is to maintain and rehabilitate the existing roadway systems rather than to build new roads (FDOT 2007). Given this recent trend of change in roadway construction projects, this study focused mainly on 3R projects. It should be noted that DB and alternative contracting strategies are generally adopted for expediting the delivery of significant projects which have significant amount, long duration, and high complexity, as depicted in Figure 3.3 and 3.4. Amounts and durations of 3R projects in the dataset significantly vary across the project delivery methods and contracting strategies. Because the inclusion of all the projects without the classification may cause biased results, the research categorized the project data by the project characteristics through the detailed classification procedures and initial descriptive analyses.

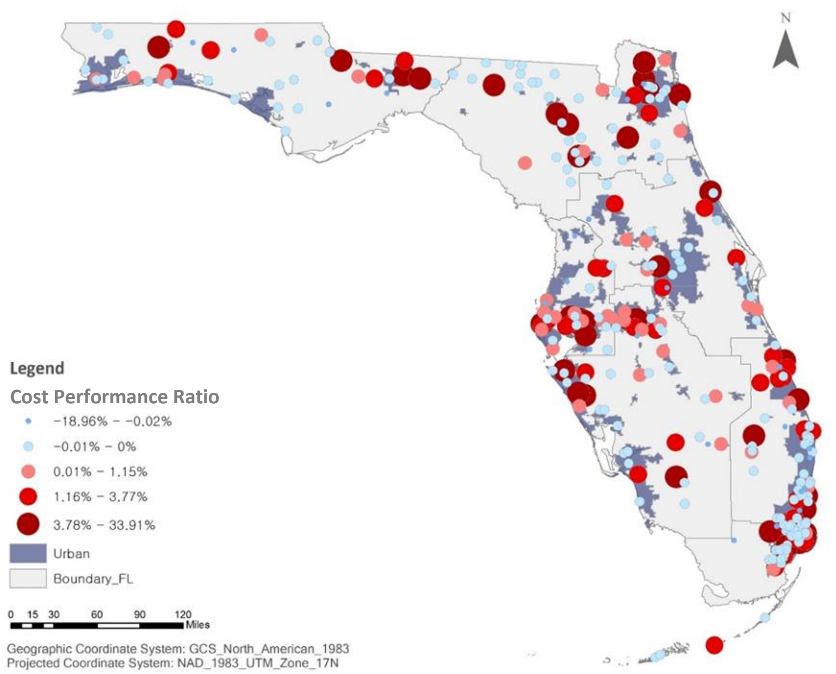


Figure 3.1. Research Area

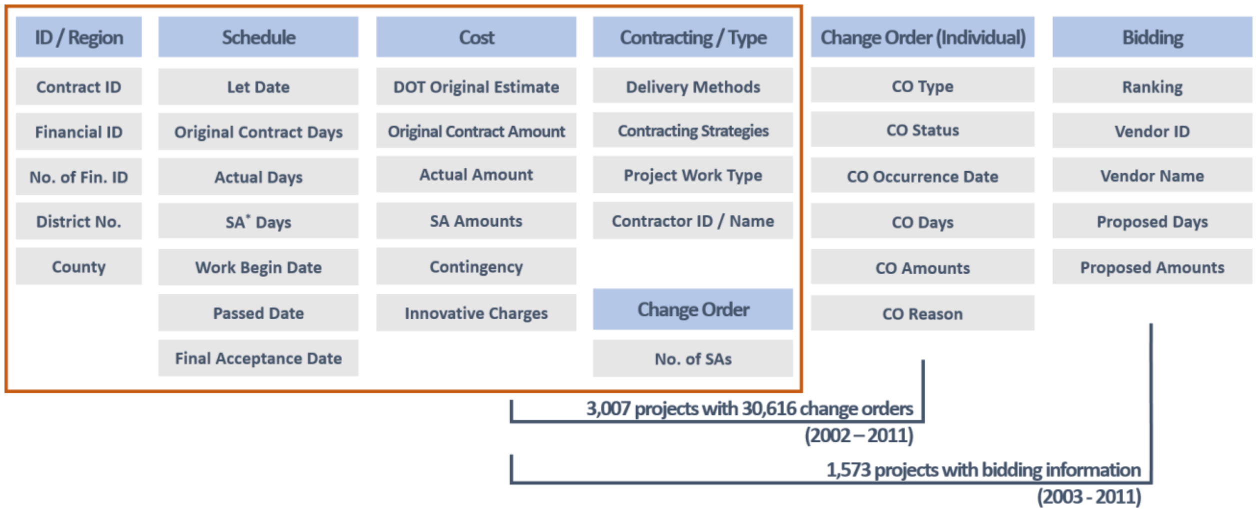
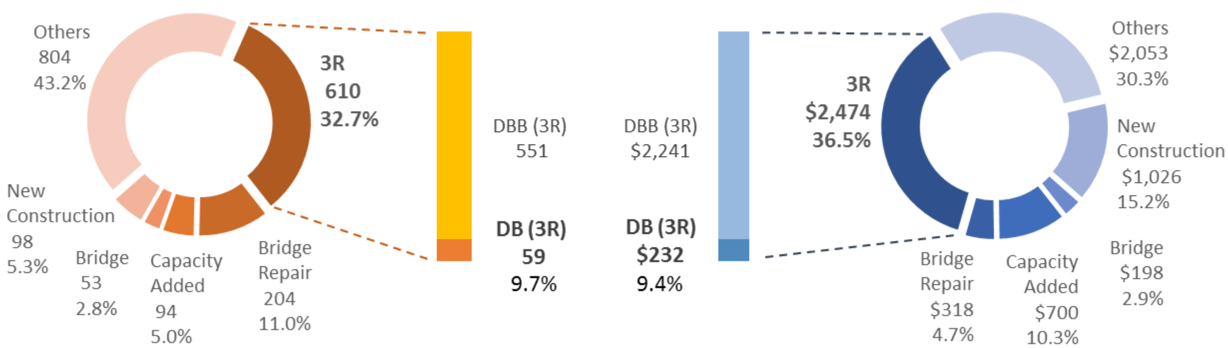


Figure 3.2. Composition of Initial Dataset



(a) Number of Projects (b) Budget Allotment ($M)

Figure 3.3. Number of Projects and Budget Allotment by Project Work Types and Project Delivery Methods

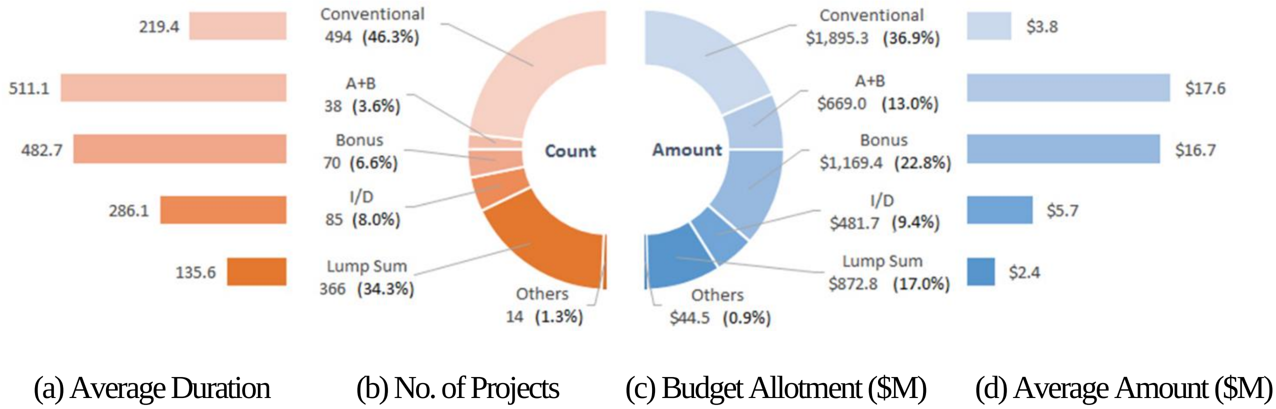


Figure 3.4. Number of Projects and Budget Allotment by Project Types and Contracting Strategies

3.2. Variable Definition and Measurement

Past studies imply that there are numerous factors that may affect project performance: from internal project factors to external environments. On the basis of the identification of factors along with the data availability, this study defined and measured a series of variables described in Table 3.1. For the sake of the comprehensiveness of the study, diverse factors were used in the analysis.

The main variables of interest in this study are schedule and cost performance and contingency adjustment. Schedule Performance Ratio (SPR) was defined by dividing the difference between original contract days and actual days by original contract days. Similarly, Cost Performance Ratio (CPR) was measured by dividing the difference between original contract amounts and actual amounts by original contract amounts. Both ratios represents the level of schedule and cost growths of the project, and were used in Chapter 4 and 5 as the dependent variables. Another important dependent variable used in Chapter 6 is Contingency

Adjustment Rate (CAdj). The FDOT's contingency policy has the combination of the fixed percent and amount along with original contract amount, as depicted in Figure 3.10 (FDOT 2017). However, the contingency policy is not effective to cope with actual cost variances, indicating that additional contingency allocation over the contingency limits in the policy is required. Therefore, CAdj is defined as the ratio of the additional contingency allocation over original contract amounts, which should be added on the contingency limits in the policy, in order to accurately and effectively address project cost variances.

Based on the literature review and the data availability, the study employed various factors that may influence project schedule and cost and consequent contingency adjustment, as summarized in Table 3.1. To capture the inherent features of the project, project size and duration were measured through the cost amount per day (ApD) as a project size indicator, and duration-long (DurL) and duration-medium (DurM) as duration dummy variables. ApD was measured by dividing original contract amounts by original contract days. For the project duration indicators, durations of projects were classified into the four quartiles. Projects ranked in over the third quartile (254 to 1717 days) were assigned as DurL. When project durations fell between the first and the third quartiles (150 to 253 days), DurM was assigned. Owner's estimate and contingency allocation can serve as parameters that represent owner's risk perception toward the project in the planning phase. For instance, if the owner anticipates higher uncertainties and risks in the project, more project cost estimates and contingency amounts would be consequently budgeted. To this end, the following factors were included: the ratio of DOT estimate for original contract amounts (EOCA), the ratio of contingency difference to DOT estimate (CDE), and the ratio of contingency difference to original contract amounts (CDO).

The main objective of this study is to investigate the effectiveness of alternative project delivery method and contracting strategies. Therefore, they were employed in a form of dummy variables: DB (DB), A+B (Cont_A+B), no excuse bonus (Cont_BN), incentive/disincentive (Cont_ID), and lump sum (Cont_LS).

Letting information would either spur or distract contractors' bidding participation, consequently, affecting the level of bidding competition and consequent bidding behavior. To take this into account, the variables pertinent to annual and monthly letting information were included: the ratio of the original contract amounts of the project for total annual letting amounts (PercALA), number of concurrent monthly lettings (ConcML), and concurrent monthly letting amount (ConcMLA). The factors related to contractors' bidding behavior can be indicators for bidding competition level and contractors' risk perception toward the project. Therefore, the study employed the ratio of bidding to original contract amount (BOA), number of biddings (NB), and standardized standard deviation of bidding amounts (SDBA).

It is commonly perceived that the expertise and available resources of the contractor can influence project performance. This study ranked contractors by their total original contract amounts of awarded projects. The study identified the contractors ranked in top 30 as major contractors and others as non-major contractors. In comparison with the Engineering News-Record's Top 400 Contractors announced during the research period, which were ranked according to revenue, the ranks of both this study and Engineering News-Record showed the high similarity (Engineering News-Record 2015). Hence, the dummy variable of major contractor (Maj) was included as an indicator of the contractor's expertise and resources.

During the research period between 2002 and 2011, there occurred the economic crisis in 2008 and its consequences were substantial for many industries and firms, including the construction industry and contractors. Therefore, this economic condition change during the period should be taken into account. Moreover, construction projects may be also influenced by the surrounding economic environments. For instance, the contractor would be desperate for the project under the economic recession, demonstrating better performance (Kometa et al. 1994). To this end, the study used the economic recession (Rec) factor in the form of a dummy variable: when projects were let since 2008, 1 was assigned.

Lastly, for reflecting the performance impacts of a change order, which is one of the major themes of this study, a series of the change order factors were measured and employed. In Chapter 4, occurrence timing (Timing), schedule change order days (SCR), and cost change order amounts (CCR) of individual change order were employed in quantitative models. Timing was measured by dividing timing point length of individual change order occurrence date from project letting date by total project duration, letting date to completion date. SCR and CCR is the ratio of day and cost changes caused by individual change order for original contract days and amounts, respectively. In the following Chapter 5 and 6, the aggregated values of change order magnitude and occurrence frequency were used, including total schedule change order ratio (TSCR), total cost change order ratio (TCCR), and change order frequency (Freq). TSCR and TCCR were calculated by dividing total day and cost changes by original contract days and amounts, respectively. Freq is a total number of change order of the project.

Table 3.1. Summary of Variables Studied

Variable		Acronym	Unit	Measurements
Performance (Dependent)	Schedule Performance Ratio	SPR	%	(Actual days – original contract days) / original contract days
	Cost Performance Ratio	CPR	%	(Actual amounts – original contract amounts) / original contract amounts
Contingency Adjustment (Dependent)	Contingency Adjustment Rate	CAdj	%	(Cost Variance – maximum contingency amounts in policy) / Original Contract Amounts *: 0 if actual cost variance is negative
Project Characteristics	Amount per Day	ApD	$mil.	Original contract amounts / original contract days
	Duration – Long	DurL	-	1 if duration is over the 3rd quartile (long 25%), 0 otherwise
	Duration - Medium	DurM	-	1 if duration is between 1st quartile and 3rd quartiles (medium 50%), 0 otherwise
DOT Estimate	DOT Estimate to Original Contract Amounts	EOCA	%	DOT's initial estimate / original contract amounts
Contingency	Contingency Difference to DOT Estimate	CDE	%	(Contingency amounts – maximum contingency amounts in policy) / DOT's initial estimate
	Contingency Difference to Original Contract Amounts	CDO	%	(Contingency amounts – maximum contingency amounts in policy) / Original Contract Amounts
Project Delivery Method	DB	DB	-	1 if project delivery method is DB, 0 otherwise
Contracting Strategies	A+B	Cont_AB	-	1 if contracting strategy is A+B, 0 otherwise
	No Excuse Bonus	Cont_BN	-	1 if contracting strategy is no excuse bonus, 0 otherwise
	Incentive/ Disincentive	Cont_ID	-	1 if contracting strategy is incentive/disincentive, 0 otherwise
	Lump Sum	Cont_LS	-	1 if contracting strategy is lump sum, 0 otherwise
Letting	Amount Percent to Total Annual Letting Amounts	PercALA	%	Original contract amounts / total annual letting amounts
	Number of Concurrent Monthly Lettings	ConcML	#	Total number of lettings in the same month
	Concurrent Monthly Letting Amount	ConcMLA	$bil.	Total letting amounts in the same month

Table 3.1. Summary of Used Variables (continued)

Variable		Acronym	Unit	Measurements
Letting	Amount Percent to Total Annual Letting Amounts	PercALA	%	Original contract amounts / total annual letting amounts
	Number of Concurrent Monthly Lettings	ConcML	#	Total number of lettings in the same letting month
	Concurrent Monthly Letting Amount	ConcMLA	$bil.	Total letting amounts in the same month
Bidding	Bidding to Original Amount	BOA	%	Winning bidding amounts / original contract amounts
	Number of Bidding	NB	#	Total number of biddings tendered to the project
	Standardized Standard Deviation of Bidding Amounts	SDBA	%	Standardized Standard Deviation of All Bidding Amounts
Contractor	Major Contractor	Maj	-	1 if the awarded contractor is ranked in top 30, 0 otherwise
Economic Environment	Economic Recession	Rec	-	1 if letting year is 2008 or later, 0 otherwise
Change Order	Total Schedule Change Order Ratio	TSCR	%	Total schedule change order amounts / original contract amounts
	Total Cost Change Order Ratio	TCCR	%	Total cost change order amounts / original contract days
	Schedule Change Order Ratio	SCR	%	Schedule change order days caused by individual change order / original contract days
	Cost Change Order Ratio	CCR	%	Cost change order amounts caused by individual change order / original contract amounts
	Change Order Occurrence Timing	Timing	%	Timing point length of each change order occurrence / total project duration
	Change Order Frequency	Freq	#	Total number of change orders

3.3. Descriptive Analysis

The initial dataset of 3,007 roadway construction projects obtained from the FDOT formed the primary sample for this study. Table 3.2 provides the descriptive statistics for the initial dataset. However, the research area of this study is 3R projects under project delivery methods (DB and DBB) and contracting strategies (conventional, A+B, no excuse bonus, incentive/disincentive, and lump sum). Through the classification procedure, irrelevant data points were excluded to meet each chapter's research objective. In turn, a total of 610 3R projects, which were under DB and DBB project delivery methods, were used in Chapter 4. Likewise, Chapter 5 and 6 employed a total of 1,053 3R projects that included contracting strategies of conventional, A+B, no excuse bonus, incentive/disincentive, and lump sum. In the rest of this section, descriptive statistics for several key features were discussed separately.

Table 3.2. Descriptive Statistics of Variables

Variable		N	Mean	Std. Dev.	Min	Max
Performance	Schedule Performance Ratio	3007	0.177	0.447	-1.000	5.333
	Cost Performance Ratio	3007	0.030	0.123	-0.987	1.536
Contingency Adjustment	Contingency Adjustment Rate	3007	0.022	0.054	0.000	1.398
Project Characteristics	Amount per Day	3007	0.013	0.014	0.000	0.279
	Duration – Long	3007	(Yes:	25.07%)	(No:	74.93%)
	Duration - Medium	3007	(Yes:	49.75%)	(No:	50.25%)
DOT's Estimate Contingency	DOT Estimate to Original Contract Amounts	1423	0.196	0.255	-0.482	0.997
	Contingency Difference to DOT Estimate	1440	0.000	0.007	-0.026	0.075
	Contingency Difference to Original Contract Amounts	1468	0.007	0.031	-0.025	0.950

Table 3.2. Descriptive Statistics of Variables (continued)

	Variable	N	Mean	Std. Dev.	Min	Max
Delivery Method	DB	1863	(Yes:	16.26%)	(No:	83.74%)
Contracting Strategies	A+B	3007	(Yes:	2.79%)	(No:	97.21%)
	No Excuse Bonus	3007	(Yes:	4.19%)	(No:	95.81%)
	Incentive/Disincentive	3007	(Yes:	7.08%)	(No:	92.92%)
	Lump Sum	3007	(Yes:	29.63%)	(No:	70.37%)
Letting	Amount Percent to Total Annual Letting Amounts	2988	0.003	0.010	0.000	0.363
	Number of Concurrent Monthly Lettings	3007	30.437	9.621	1	49
	Concurrent Monthly Letting Amount	3007	135.341	107.424	0.050	489.390
Bidding	Bidding to Original Amount	1500	0.048	0.068	-0.963	0.530
	Number of Bidding	1509	4.347	2.379	1	18
	Standardized Standard Deviation of Bidding Amounts	1511	0.151	0.222	0	6.9181
Contractor	Major Contractor	1509	(Yes:	58.71%)	(No:	41.29%)
Economic Environment	Economic Recession	3007	(Yes:	27.90%)	(No:	72.10%)
Change Order	Total Schedule Change Order Ratio	3007	0.061	0.189	-0.590	3.439
	Total Cost Change Order Ratio	3007	0.027	0.095	-1.000	1.215
	Schedule Change Order Ratio	31105	0.018	0.054	-0.800	0.964
	Cost Change Order Ratio	31105	0.002	0.021	-0.987	0.760
	Change Order Occurrence Timing	30109	0.625	0.239	0.000	1.000
	Change Order Frequency	3007	10.035	13.392	0	139

3.3.1. Schedule and Cost Overruns and Change Order

The study firstly examined the frequency of schedule delays and cost overruns in the initial dataset of 3,007 highway projects. The most favorable case is that the project is completed within planned duration and budget. However, it was seen that only 16.3 percent met both targeted duration and budget. The cases within planned duration but over budget accounted for only 15.1 percent of total projects. Similarly, 23.2 percent of total projects satisfied initial budget plan while having schedule delays. More seriously, 1,365 out of 3,007 projects, which accounted for 45.4 percent of total projects, experienced schedule delays and cost overruns simultaneously. This reaffirms that schedule and cost growths are ubiquitous and inevitable in any construction projects.

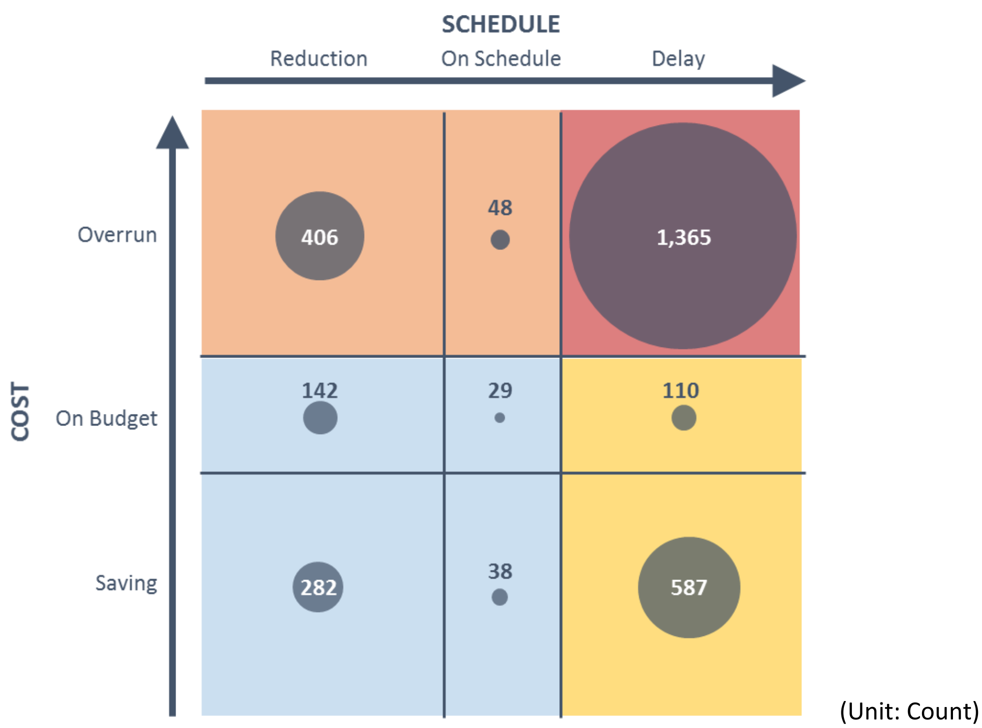


Figure 3.5. Aspects of Schedule and Cost Performance

Change orders are considered as a main culprit of schedule delays and cost overruns. Some may have impacts on project schedule and/or cost, while some do not. The FDOT classifies change orders into 11 categories, as summarized in Table 3.3. When additional money is granted for an unexpected work, a contingency supplemental agreement (CN) is made. If a specified additional work that requires additional money and/or days occurs, a supplemental agreement (SA) is provided. To address additional cost and days caused by a disputed claim, a unilateral supplemental agreement (UN) is granted. These three change order types were identified as change orders involving schedule and cost changes. With respect to schedule related change orders, there are five types. Changed conditions (CO) are an agreement for conditions that are different from those in the bidding phase. When schedule needs to be extended for the completion of the project, the owner provided a time extension agreement (EA). Holidays can be a significant factor for schedule delays. In the case of time extension due to holidays, a holiday time extension (HTEX) is granted. For the case of inclement weather, such as hurricane and heavy rain which are beyond the prediction and control of project participants, the provision of weather days time granted (WE) is inevitable. A contingency work order times adjustment is for days granted on the original contingency pay item or on a contingency supplemental agreement. There are also change order types that have no impacts on schedule and cost of the project. For the purposed of participation modification of already paid items, modifying pay item participation (MPRT) is applied. Also, when pay item’s financial project number needs to shift, the owner uses movement of item within contract (SPAD). Lastly, in the case that specification change should be documented, work order for specification change only (SPEC) is used.

The initial data sample of 3,007 projects had a total of 30,616 change orders. Of those, 3R projects experienced a total of 13,461 change orders, which means 3R projects had an average of 12.2 change orders. To better understand the natures of change orders, as illustrated in Figure 3.6, the study visualized each change order type's schedule and cost impacts and occurrence frequency in 3R projects. Five percent of those change orders did not have any impact on either project days or amounts (change order type: SPAD and SPEC). Change order types only pertinent to schedule change accounted for 78.9 percent of the total change orders (CO, EA, HTEX, WE, WOTA). Although WE was the most frequent change order type, EA was found as a change order type most significantly causing time increases (average 9.73 percent increase of original contract days). There are the three change order types that caused the concurrent increase in project days and amounts: namely CN, SA, and UN. Those three change order types had 16.1 percent of the total change orders.

Table 3.3. Change Order Types in Florida Department of Transportation

Impact	Abbrev.	Change Order Type	Description
Schedule & Cost	CN	Contingency Supplemental Agreement	Additional money granted for unexpected work
	SA	Supplemental Agreement	Additional money and/or days granted for specified additional work
	UN	Unilateral Supplemental Agreement	Document used to pay estimated value of a disputed claim
Schedule	CO	Changed Conditions	Something different than at the time of bidding
	EA	Time Extension Agreement	Days granted to complete the work
	HTEX	Holiday Time Extension	Days granted due to a holiday
	WE	Weather Days Time Granted	When days are granted due to inclement weather
	WOTA	Contingency Work Order Time Adjustment	Days granted on the original contingency pay item or on a contingency SA

Table 3.3. Change Order Types in Florida Department of Transportation (continued)

Impact	Abbrev.	Change Order Type	Description
None	MPRT	Modifying Pay Item Participation	Used for changing participation on contract items that have already been paid. Administrative action only. Does not require outside approval
	SPAD	Movement of Item within Contract	Moving pay items from one financial project number to another. Administrative action only. Does not require outside approval
	SPEC	Work Order for Specification Change Only	Used to document any specification changes

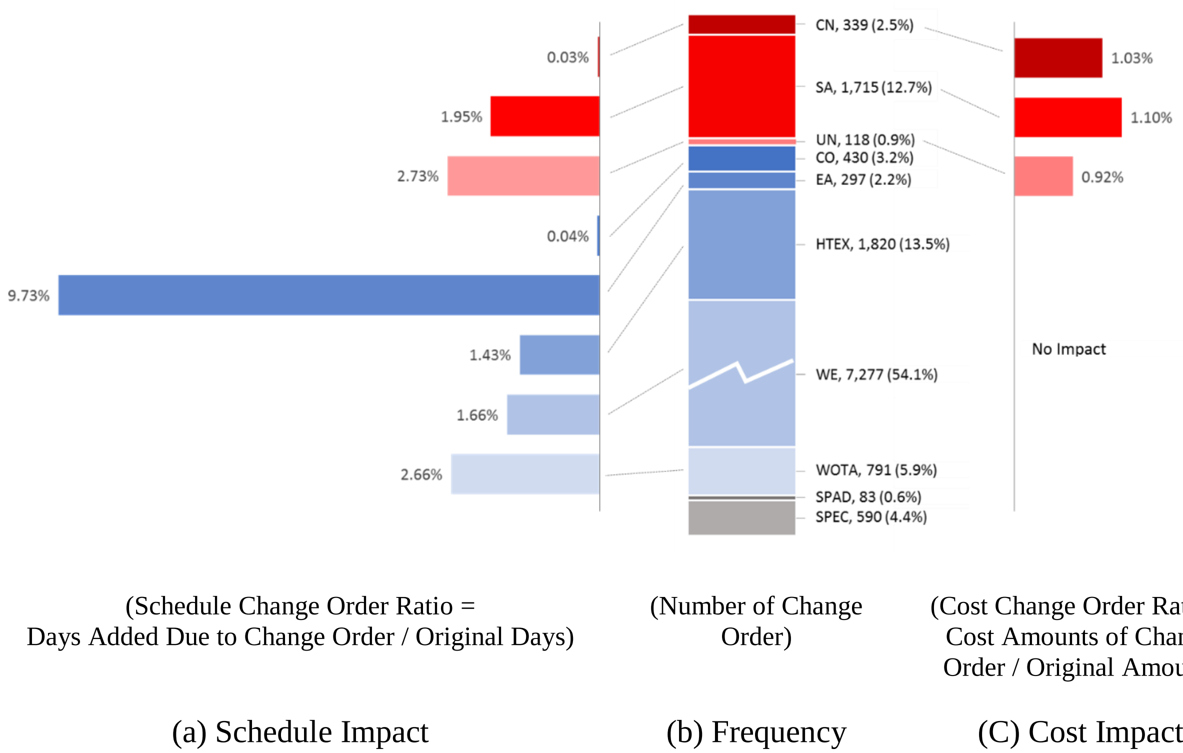


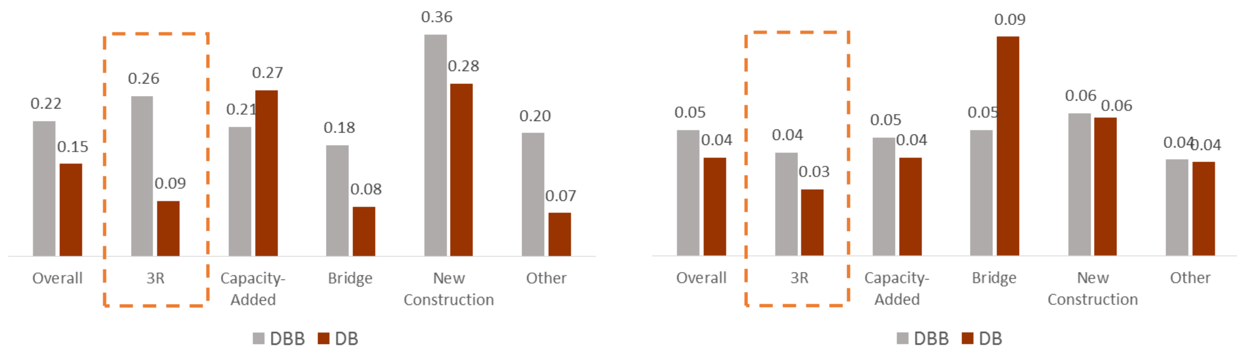
Figure 3.6. Average Schedule and Cost Change by Change Order Types in 3R Projects

3.3.2. Project Delivery Methods

Table 3.4 represents the descriptive statistics for 3R projects under two project delivery methods, DBB and DB. The values, in overall, show that DB had more favorable performance and less change order impacts. This was also supported by the results from the t-test in Table 4.1. It should be noted that the primary goal of DB is to accelerate project delivery. The schedule related statistics in Table 3.4 shows that DB was effective in its intention for shortening project duration. Figure 3.7 provided average schedule and cost impacts of DBB and DB projects across project work types. This also supports that DB had less schedule and cost impacts from change orders.

Table 3.4. Descriptive Statistics versus Project Delivery Methods in 3R projects

Delivery Method	Variable	Mean	Std. Dev.	Min	Max	N
DBB	SPR	0.250	0.361	-1.000	2.172	551
	CPR	0.032	0.147	-0.977	1.536	
	TSCR	0.072	0.166	-0.290	1.417	
	TCCR	0.034	0.094	-0.164	0.995	
	Freq	12.2	14.0	0	124	
DB	SPR	0.126	0.336	-0.548	1.217	59
	CPR	0.047	0.112	-0.194	0.614	
	TSCR	0.044	0.138	-0.172	0.967	
	TCCR	0.013	0.167	-1.000	0.615	
	Freq	5.9	8.2	0.000	53.000	
Total	SPR	0.238	0.360	-1.000	2.172	610
	CPR	0.034	0.144	-0.977	1.536	
	TSCR	0.069	0.164	-0.290	1.417	
	TCCR	0.032	0.104	-1.000	0.995	
	Freq	11.6	13.7	0	124	



(Schedule Change Order Ratio =
Days Added Due to Change Order / Original Days)

(a) Schedule Impact

(Cost Change Order Ratio =
Cost Amounts of Change Order / Original Amount)

(b) Cost Impact

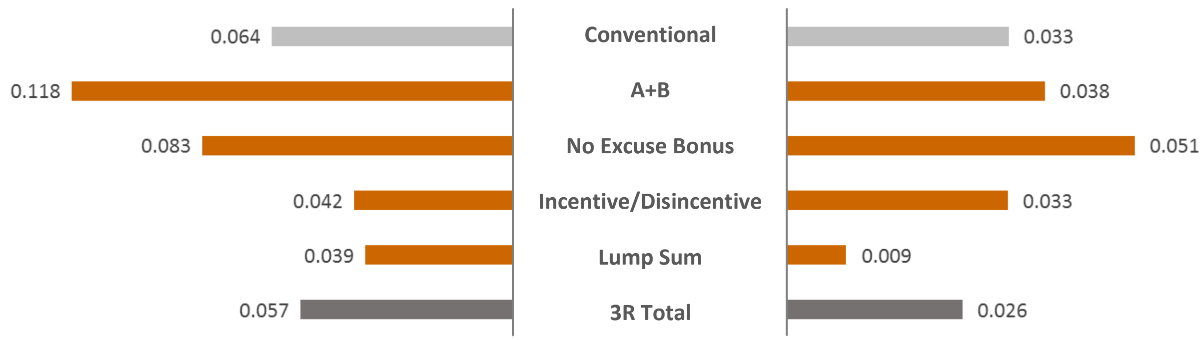
Figure 3.7. Change Order Impact on Schedule and Cost by Project Types and Project Delivery Methods

3.3.3. Alternative Contracting Strategies

The effectiveness of alternative contracting strategies is one of the main focuses in this study. Most of them are intended to pursue fast-tracking of project completion: specifically, A+B, no excuse bonus, and incentive/disincentive. However, the descriptive statistics of some alternative contracting strategies in Table 3.5 and Figure 3.8 depict contrary aspects when compared to those of the conventional contracting strategy, to the extent. Particularly, all the average values of A+B exceeded those of other alternative contracting strategies as well as the conventional contracting strategies. No excuse bonus had less schedule delays but more cost overruns than the conventional contracting strategy. Incentive/disincentive showed the most desirable aspects, in general. Given the relatively simple project scope and low project risks, lump sum is expected to be less subject to schedule and cost changes. The statistics of lump sum seem to coincide with such expectation.

Table 3.5. Descriptive Statistics versus Contracting Strategies in 3R Projects

Contracting Strategy	Variable	Mean	Std. Dev.	Min	Max	N
Conventional	SPR	0.256	0.354	-1.000	2.172	494
	CPR	0.028	0.150	-0.977	1.536	
	TSCR	0.064	0.150	-0.250	1.045	
	TCCR	0.033	0.094	-0.164	0.995	
	Freq	12.3	13.2	0	90	
A+B	SPR	0.241	0.252	-0.168	0.866	38
	CPR	0.075	0.093	-0.150	0.366	
	TSCR	0.118	0.138	-0.021	0.607	
	TCCR	0.038	0.064	-0.020	0.339	
	Freq	30.4	21.0	0.000	76.000	
No Excuse Bonus	SPR	0.109	0.323	-0.350	1.057	70
	CPR	0.048	0.131	-0.264	0.662	
	TSCR	0.083	0.201	-0.046	0.967	
	TCCR	0.051	0.112	-0.044	0.672	
	Freq	26.8	28.1	0	124	
Incentive/Disincentive	SPR	0.056	0.288	-0.280	1.116	85
	CPR	0.027	0.089	-0.182	0.296	
	TSCR	0.042	0.127	0.000	0.848	
	TCCR	0.033	0.063	-0.055	0.354	
	Freq	14.4	12.0	0	59	
Lump Sum	SPR	0.149	0.364	-0.988	1.520	366
	CPR	0.027	0.082	-0.777	0.606	
	TSCR	0.039	0.125	-0.378	1.417	
	TCCR	0.009	0.072	-1.000	0.254	
	Freq	7.6	7.5	0	48	
Total	SPR	0.192	0.354	-1.000	2.172	1,053
	CPR	0.031	0.123	-0.977	1.536	
	TSCR	0.057	0.145	-0.378	1.417	
	TCCR	0.026	0.086	-1.000	0.995	
	Freq	12.5	14.6	0	124	



(Schedule Change Order Ratio = Days Added Due to Change Order / Original Days)

(Cost Change Order Ratio = Cost Amounts of Change Order / Original Amount)

(a) Schedule Impact

(b) Cost Impact

Figure 3.8. Change Order Impact on Schedule and Cost by Contracting Strategies in 3R projects

3.3.4. Owner's Estimate versus Bidder's Amounts

The owner and the contractor would have different risk perspective even toward the same project. The gap between their risk perceptions could be intensified or narrowed along with different contracting strategy. Such difference in risk perceptions toward contracting strategies between those two parties could be represented in their initial estimates. Figure 3.8 provides the two stakeholders' estimate difference from original contract amounts, which can be an indicator of the agreed or market price of the project. It is commonly known that STAs usually estimate project cost generously and contractors largely attempt to lower their bidding amounts up to their available limits to win the bidding. Even considering their different approaches, Figure 3.9 shows that there were significant differences in the degree of risk perceptions between the two sides. Intriguingly, it seems that the both anticipate A+B projects require more costs than original contract amounts.

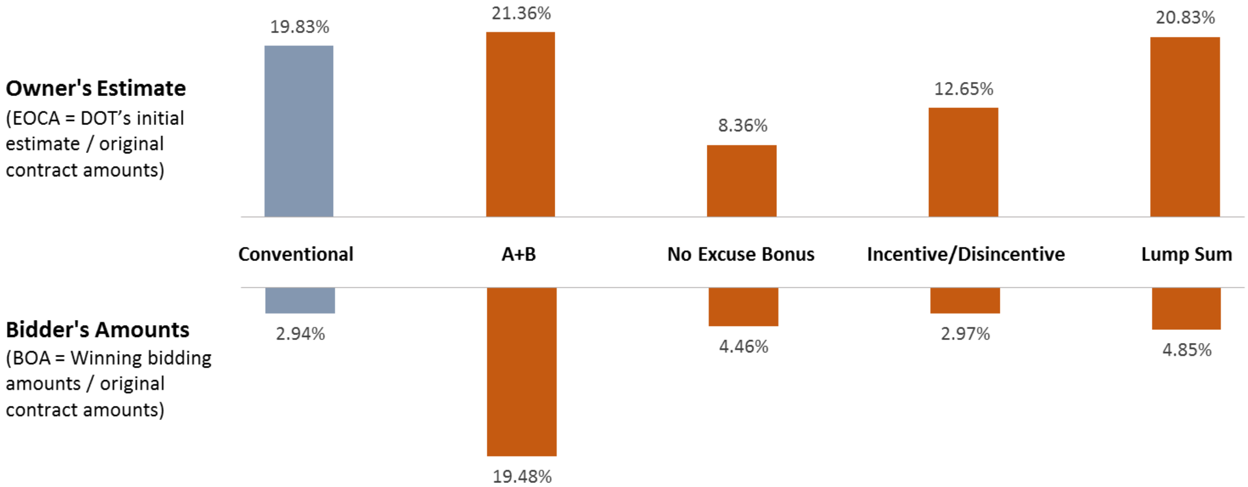


Figure 3.9. Owner's Estimate versus Bidder's Bidding Amounts by Contracting Strategies in 3R Projects

3.3.5. Contingency

The FDOT (2017) has a unique contingency policy consisting of fixed rates and amounts by original contract amounts. Figure 3.10 clearly illustrates the significant discrepancy between contingency amount limits in their policy and actual cost variances. However, the FDOT assigned additional contingency amounts (CDO) over the limits in the policy. Although CDO would be intended to cope with anticipated excessive risks, Figure 3.11 shows that it did not complement the actual required costs, CAdj, by contracting strategies. To this end, contingency adjustment needs to be revised for the sake of realistic contingency practice.

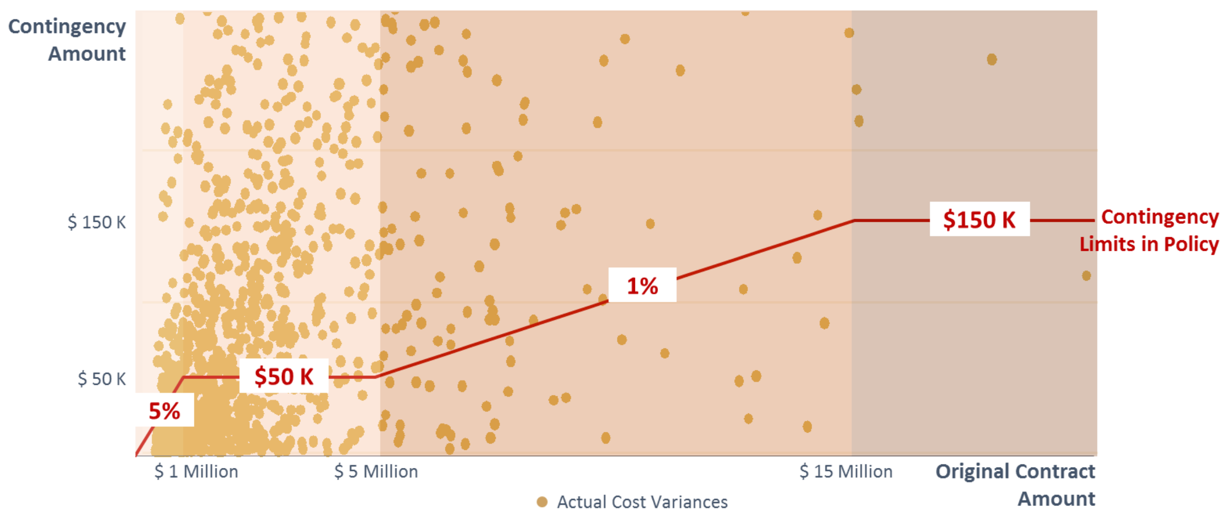


Figure 3.10. Contingency Policy versus Actual Cost Variances in 3R Projects

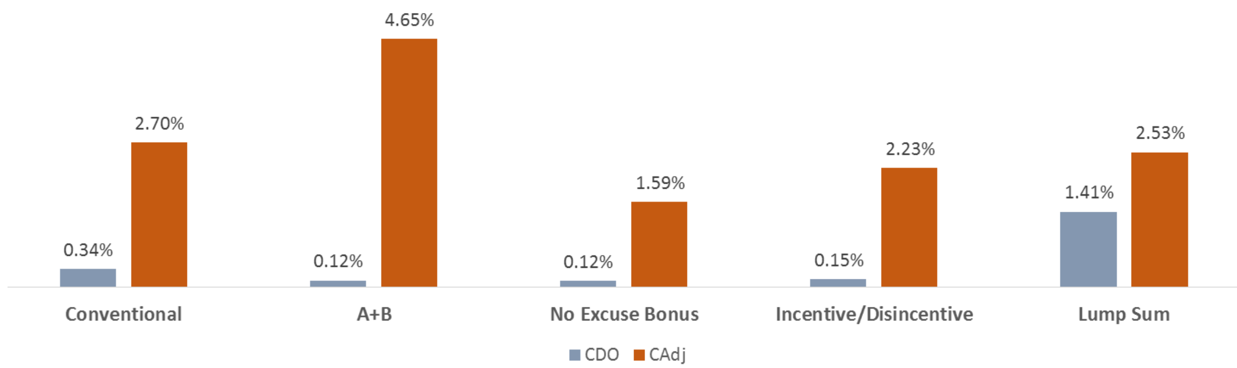


Figure 3.11. Actual Additional Contingency Allocation versus Required Additional Contingency by Contracting Strategies in 3R Projects

3.3.6. Major and Non-Major Contractors

As stated earlier, the expertise and resources of the contractor can be also a significant factor affecting project performance. The construction industry appears to be a competitive market because it is in nature a bidding market where contractors keenly compete. However, the reality is that the construction industry is akin to an oligopolistic market (OECD 2008). Bidding award information in the dataset also represents such an oligopolistic aspect. Specifically, major contractors (top 30) displayed higher contract winning probability and, consequently, were awarded 78.0 and 81.9 percent of the total contract amounts of the entire projects and 3R projects, respectively, as shown in Figure 3.12 and Table 3.6. Therefore, a single major contractor's impact can be significant. Considering their expertise, size, and resources, they are expected to be more successful in restraining schedule delays and cost overruns than non-major contractors. However, all the average values of SPR, CPR, TSCR, and TCCR in 3R projects were inferior to those of non-major contractors. This would be attributed to the fact that they usually carry out large and complicated projects.

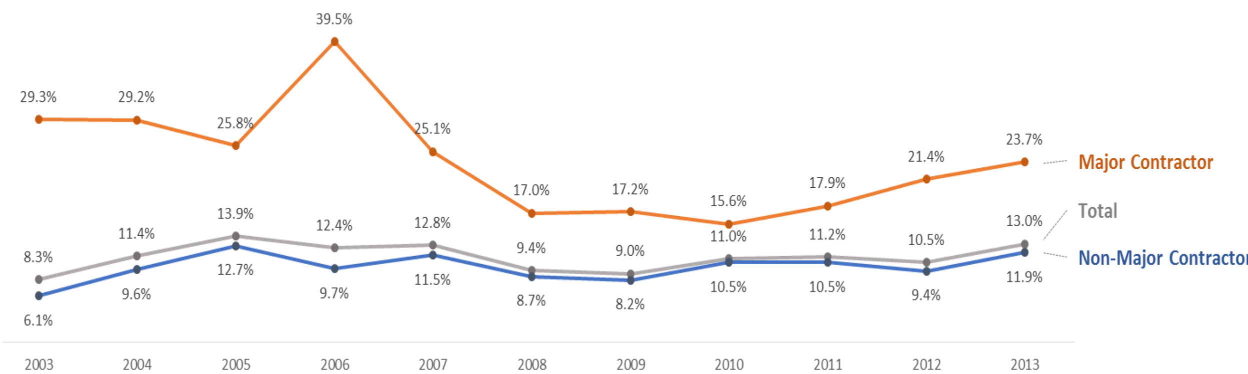


Figure 3.12. Bid Winning Trend of Major and Non-Major Contractors by Letting Year

Table 3.6. Descriptive Statistics by Major and Non-Major Contractors

Project Work Type	Contractor	No. of Projects	Total Awarded Amounts ($M)	SPR	CPR	TSCR	TCCR
Total	Major	886	5,475.34	16.94%	2.74%	4.94%	2.12%
	Non-Major	623	1,543.71	21.38%	1.96%	7.16%	2.10%
3R	Major	518	3,059.89	19.60%	2.49%	5.34%	2.06%
	Non-Major	224	677.12	16.96%	0.70%	4.31%	1.46%
Bridge	Major	17	160.56	9.20%	4.00%	3.83%	2.07%
	Non-Major	25	56.79	22.10%	3.14%	4.37%	1.69%
Bridge Repair	Major	14	62.56	21.78%	3.33%	2.69%	2.56%
	Non-Major	34	85.54	23.95%	4.33%	7.04%	1.90%
Capacity Added	Major	49	332.66	9.40%	3.81%	3.31%	2.67%
	Non-Major	34	91.47	10.58%	1.70%	2.14%	1.25%
New	Major	34	694.69	18.22%	8.38%	8.56%	5.29%
	Non-Major	20	173.36	28.49%	6.27%	11.59%	4.23%
Others	Major	254	1,164.98	13.05%	2.17%	4.14%	1.69%
	Non-Major	286	459.44	25.23%	2.29%	9.93%	2.61%

3.3.7. Economic Recession

The construction industry is inherently prone to changes in economic environments. Consequently, contractors' behavior, especially toward project performance management, is highly likely to be subject to economic condition changes. To take an example, as depicted in Figure 3.13, after the economic recession in 2008, the bidding completion became keener.

It seems that the economic crisis evoked the improvement of contractors' performance management. Compared to the performance parameters before that economic shock, contractors demonstrated better performance in both project schedule and cost, as shown in Table 3.7. However, this might be also due to the decrease in the letting of huge-scaled and complicated projects.

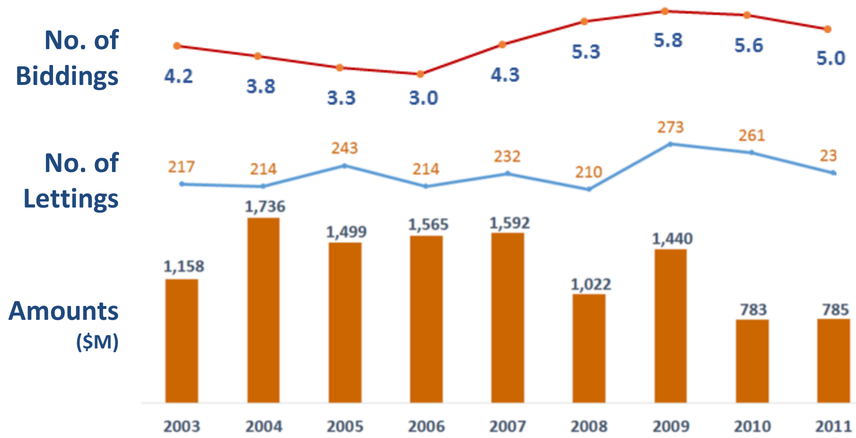


Figure 3.13. Letting and Bidding Trend Change by Letting Year

Table 3.7. Project Performance Change by Economic Recession

Period	Average Amounts ($M)	No. of Bidding	SPR	CPR	TSCR	TCCR	Freq
Total	4.84	4.17	19.39%	3.21%	5.68%	2.59%	12.3
2003-2007	5.96	3.64	21.58%	4.17%	6.75%	3.13%	12.8
2008-2011	2.25	5.12	14.33%	0.98%	3.20%	1.33%	11.1

3.4. Summary and Conclusions

This chapter discussed the characteristics and descriptive analysis results of the research dataset and variables used in the study. Given the recent roadway construction trend shift from new construction to rehabilitation, this study focused on 3R projects. In an attempt to derive comprehensive analysis results, through data classification and measurements, the study identified various candidate factors. The study also conducted a series of descriptive analyses to examine the aspects of the key factors in the study. The notable findings in this chapter are summarized as the following:

Schedule delays and cost overruns were prevalent: 84.7 percent of the total projects in this study experienced schedule and/or cost growths. With respect to the effectiveness of alternative project delivery method, DB seemed to have less schedule delays and cost overruns than the traditional DBB. Alternative contracting strategies showed somewhat contradictory aspects against its intended purpose in the acceleration of project completion. It was seen that the owner and contractor had significantly different estimates, that is, different risk perceptions. Contingency practice was not effective to address actual cost variances. Unlike the common belief, projects with major contractors appeared to have more schedule and cost growths than those of non-major contractors. Finally, projects tendered since the economic recession in 2008 looked to experience lower increases in schedule and cost.

However, it should be noted that the stated findings in this chapter were only based on the initial descriptive analysis. Therefore, for the performance impacts of each key features, statistical analysis results in the later chapters should be referred.

4. PERFORMANCE IMPACTS OF PROJECT DELIVERY METHODS

This chapter addressed the first research objective that sought the quantification of change order magnitude and occurrence timing impacts under two project delivery methods, DB and DBB. To achieve the research objective in this chapter, the study conducted a t-test and multiple linear regression analysis using 610 3R projects.

4.1. Project Delivery Methods and Change Order

Since U.S. highway systems have been significantly obsolete and deteriorated, consequent rehabilitation works have been a major concern of every STAs over decades (Choi and Kwak 2012; Choi 2010; Napolitan and Zegras 2008). However, roadway rehabilitation projects often cause additional traffic delays, public inconvenience, and economic losses in surrounding communities and business (Choi and Kwak 2012; Choi et al. 2011; Choi 2010). Therefore, acceleration of project completion can play a pivotal role in minimizing those unfavorable impacts of roadway construction projects. To this end, alternative project delivery method, such as DB, has been widely adopted in highway renewal projects over the past two decades. However, research findings about its effects on project performance are inconsistent.

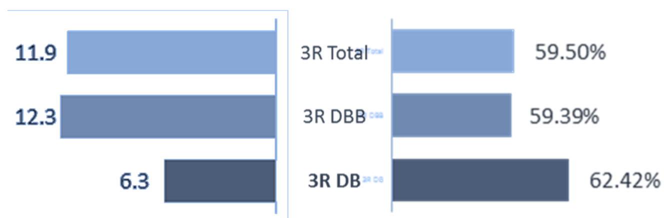
In addition, due to the inherently uncertain nature of construction projects, change orders are prevalent and serve as a main cause of schedule delays and cost overruns productivity (Assaf and Al-Hejji 2006; Chester and Hendrickson 2005; Fayek et al. 2003; Fayek and Oduba 2005; Moselhi et al. 2005; Wichern 2004). Hence, considerable amounts of past studies have focused on unfavorable impacts of change orders from various research perspectives. However, there is no available information about the timing impacts of change order occurrence on project performance. The effect of any event, especially when it is unexpected and undesirable, can vary depending on its occurrence timing. In an attempt to fill the above two gaps in the current knowledge, the study pursued the development of quantitative models that can predict the impacts of change order magnitude and occurrence timing on project schedule and cost under given project delivery methods. Pertinent descriptive and comparative analyses were also conducted to provide explicit information about the effectiveness of the alternative delivery method, DB.

4.2. Project Performance Comparison of Project Delivery Methods

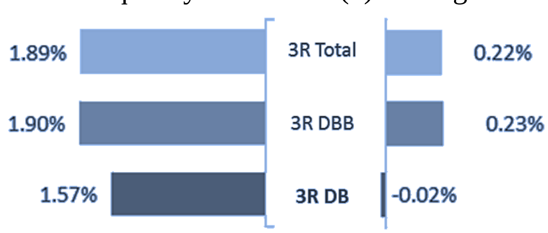
Prior to investigating timing impacts of change orders on project cost and schedule under different project delivery methods, a number of initial comparative analyses were conducted to examine aspects of change order magnitude, frequency, occurrence timing, and project performance between DB and DBB methods.

Figure 4.1 (a)-(d) illustrate frequency and occurrence timing of change orders, and project cost and schedule performance between the two project delivery methods. It is commonly perceived that projects under a DB delivery method are likely to experience more frequent and influential change orders due to a lack of the design integrity in the initial project commencement. However, DB projects analyzed in this study showed nearly a half of changer order frequency of DBB projects on average: as depicted in Figure 4.1 (a), 6.3 and 12.3 changer orders per project under DB and DBB, respectively. The distribution of change order frequency with 5 intervals (no, 1-5, 6-10, and over 10 change orders), as shown in Figure 4.2, also clearly illustrated that DBB projects had more change orders.

Average occurrence timing of change orders indicated that DB projects had a tendency of later occurrence: an average timing at 62.42 and 59.39 percent of the total project duration, for DB and DBB projects, respectively. When examining the distribution of change order occurrence by project quartiles, as illustrated in Figure 4.3, over 75 percent of change orders took place during the latter half of the project duration under DB, while DBB had approximately 60 percent of change orders during the later half. This later change order occurrence tendency in DB projects may attribute to the inherent nature of the DB approach. In a delivery process under DB, the construction phase starts early with uncompleted design work scopes to fast-track project delivery. Consequently, the latent factors affecting project time and cost are likely to be detected later, resulting in delayed confirmation and alteration of project design and work scopes.



(a) Average Change Order Frequency (b) Average Change Order Occurrence Timing



(c) Average Schedule Change Order Ratio (d) Average Cost Change Order Ratio

Figure 4.1. Average Change Order Frequency, Occurrence Timing, and Performance Impacts by Delivery Methods

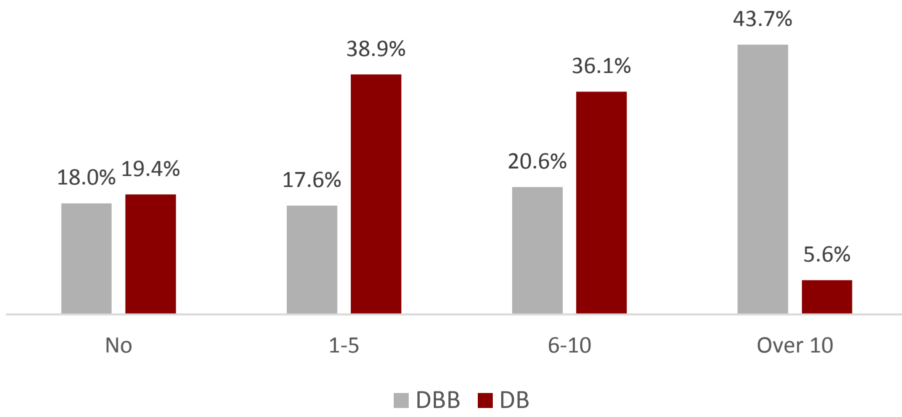


Figure 4.2. Distribution of Change Order Frequency by Project Delivery Methods

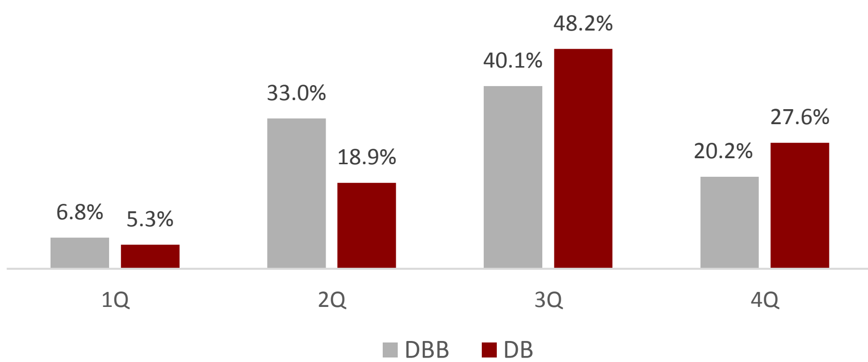
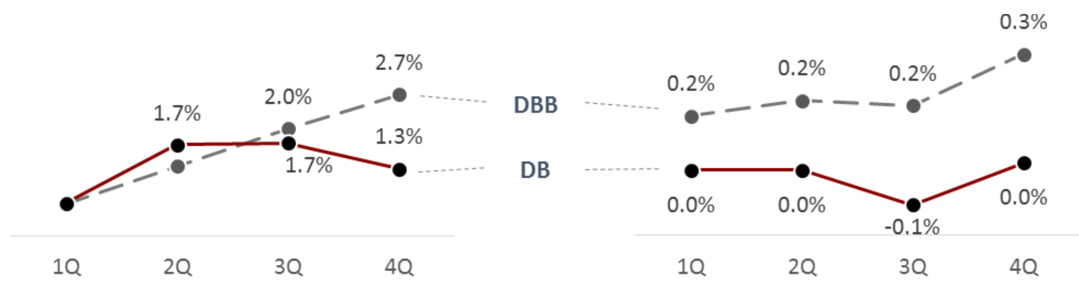


Figure 4.3. Distribution of Change Order Occurrence Timing by Project Duration Quartile

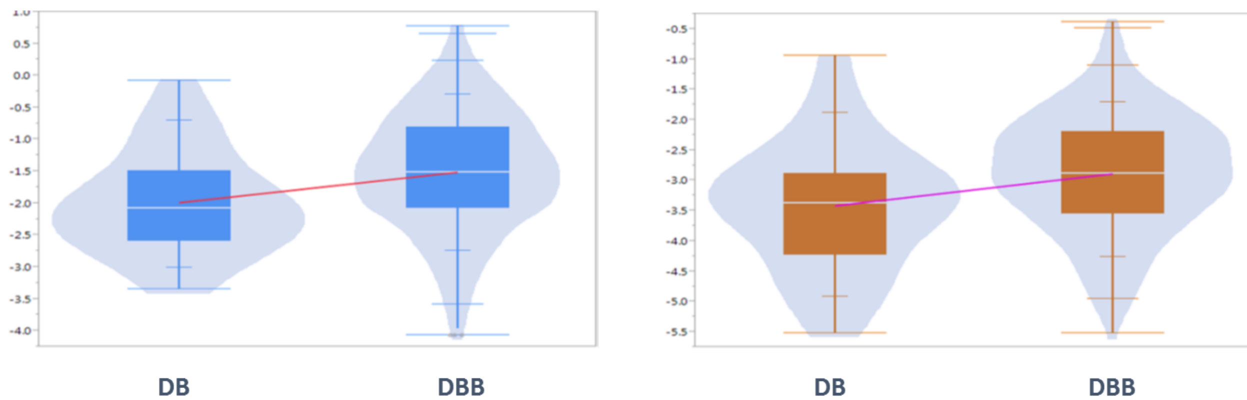
In an attempt to examine the direct impact of a change order on schedule and cost by their occurrence timing, the study also visualized the average schedule and cost change order ratios by the project duration quartiles, as given in Figure 4.1 (c), (d), and Figure 4.4. Contrary to the common notion, schedule and cost impacts of change orders under DB projects seem to be slightly lower than those under DBB projects. The average change order magnitude of DBB projects tend to obey the common notion that later occurrence of change orders has more negative impacts on project schedule and cost. On the other hand, that of DB projects showed flat or partially decreasing trends along with the project duration quartiles. However, the Tukey Honest Significant Difference (HSD) pairwise test results did not provide sufficient evidence that there was the significant difference in added days and cost by a change order. To this end, the corresponding test results were not included in this paper.



(a) Average Schedule Change Order Ratio (b) Average Cost Change Order Ratio

Figure 4.4. Change Order Cost and Schedule Ratios by Project Duration Quartile

One of the main objectives in this chapter is to test whether there are significant differences in the effectiveness on project schedule and cost between DB and DBB. To achieve this goal, this study initially used box-plots that can intuitively show the performance differences between the two project delivery methods. Figure 4.5 depicted that DB projects analyzed in this study had less schedule delays and cost overruns than traditional DBB projects. However, the data did not satisfy the normality assumption that is essential to conduct a parametric comparison analysis, that is, the Tukey HSD pairwise test. In order to address this normality violation in the data, the study applied a natural log-log transformation to both the schedule and cost performance ratio variables. As shown in Table 4.1, comparative analysis results were obtained using the Tukey HSD pairwise test. Compared to an ANOVA test that determines whether the test result is significant, the Tukey HSD test allows identifying how specific test group's means are different from each other. The results clearly provided a significant evidence that, as initially identified via box-plots, DB projects experienced less schedule delays and cost overruns. This result affirms the previous studies' findings that DB outperformed DBB in both project schedule and cost (Hale et al. 2009; Konchar and Sanvido 1998; Molenaar and Songer 1998; Songer et al. 1996).



(Schedule Performance Ratio =
Actual Days / Original Contract Days)

(a) Schedule Performance

(Cost Performance Ratio =
Actual Amount / Original Contract Amount)

(b) Cost Performance

Figure 4.5. Box-Plots of Schedule and Cost Performance by Project Delivery Methods

Table 4.1. Tukey HSD Pairwise Comparison of Schedule and Cost Performance

Variables	Level (*i*)	Level (*j*)	Difference (*i*-*j*)	Std Error	*t Ratio*	*p*>| *t* |
Log(SPR)	DB	DBB	-0.5868	0.0640	-9.17	.000
Log(CPR)	DB	DBB	-0.9837	0.1770	-5.56	.000

4.3. Model Development

The primary aim of this study in this chapter is to develop a quantitative model for the impacts of change order magnitude, frequency, and occurrence timing on project schedule and cost. To this end, the study developed two multiple linear regression models for project schedule and cost, respectively.

4.3.1. Variable Selection

To achieve the research objective, this study extracted the data of 610 3R projects, which include project delivery method information, through the data classification. Those 610 3R projects had a total of 13,710 change orders. The study measured and selected variables applicable to the intended research objective, as describe in Table 4.2. However, it should be noted that the bidding and contract procedure of DB is inherently value-based selection, which means that DB is not an open competitive bidding. Therefore, available information is highly limited. In this sense, some information, including estimate, contingency, letting, bidding, and contractor related factors, was not used in this study.

For the dependent variables, schedule and cost performance ratio variables (SPR and CPR) were used. With respect to the project characteristics variables, as depicted in Table 3.1 in Chapter 3, the study initially considered the use of ApD, DurqL, and DurqM. However, they were not statistically significant in the initial analysis. Alternatively, the study employed original contract days and amounts (OrgD and OrgA). As an indicator of project delivery methods, a dummy variable of DB was used, which was assigned 1 and 0 for DB and DBB, respectively. Aside from project delivery methods, the project may also involve alternative contracting strategies. In an attempt to isolate their likely impacts on project performance, this study assigned 1 and 0 for alternative contracting strategies and the conventional method to the corresponding dummy variable (Cont). To reflect the possible impacts of the surrounding economic environments, Rec was included in the analysis. Lastly, change order information, including TSCR, TCCR, SCR, CCR, and Timing were employed to investigate the impacts of change orders on project performance.

Table 4.2. Variables Studied

Variable		Acronym	Unit	Measurements
Performance (Dependent)	Schedule Performance Ratio	SPR	%	(Actual days – original contract days) / original contract days
	Cost Performance Ratio	CPR	%	(Actual amounts – original contract amounts) / original contract amounts
Project Characteristics	Log(Original Contract Days)	LnOrgD	#	Log-log transformed original contract days
	Log(Original Contract Amounts)	LnOrgA	$	Log-log transformed original contract amounts
Project Delivery Method	DB	DB	-	1 if project delivery method is DB, 0 otherwise
Contracting Strategies	Alternative Contracting Strategies	Cont	-	1 if contracting strategy is an alternative contracting strategy, 0 if conventional
Economic Environment	Economic Recession	Rec	-	1 if letting year is 2008 or later, 0 otherwise
Change Order	Total Schedule Change Order Ratio	TSCR	%	Total schedule change order amounts / original contract amounts
	Total Cost Change Order Ratio	TCCR	%	Total cost change order amounts / original contract days
	Schedule Change Order Ratio	SCR	%	Schedule change order days caused by individual change order / original contract days
	Cost Change Order Ratio	CCR	%	Cost change order amounts caused by individual change order / original contract amounts
	Change Order Occurrence Timing	Timing	%	Timing point length of each change order occurrence / total project duration

4.3.2. Model Development for Project Performance

Based on the identified variables in this chapter and the Eq. (1) and (2) in Chapter 1, this study developed the hypothetical model, as illustrated in Figure 4.6. This study initially hypothesized that all the changer order variables have positive impacts on project schedule and cost, meaning that later occurrence and higher magnitude of change order caused more schedule delays and cost overruns. With respect to project characteristics, it is commonly believed that projects with large amounts and longer durations usually have the higher degrees of risks, and consequently, the higher possibility of schedule delays and cost overruns. To this end, this study embraced such perception as the hypotheses for the project characteristics. In the literature, alternative project delivery method and contracting strategies are usually expected to have less schedule delays and cost overruns. Therefore, this study presumed that they have negative relationships with project schedule and cost growths. Finally, Rec was included in the hypothetical model to take into account the impacts of the economic recession on project performance. Under the economic recession, both the contactor and the owner are likely to make intensive management efforts. Therefore, negative relationships with schedule and cost growths were assumed.

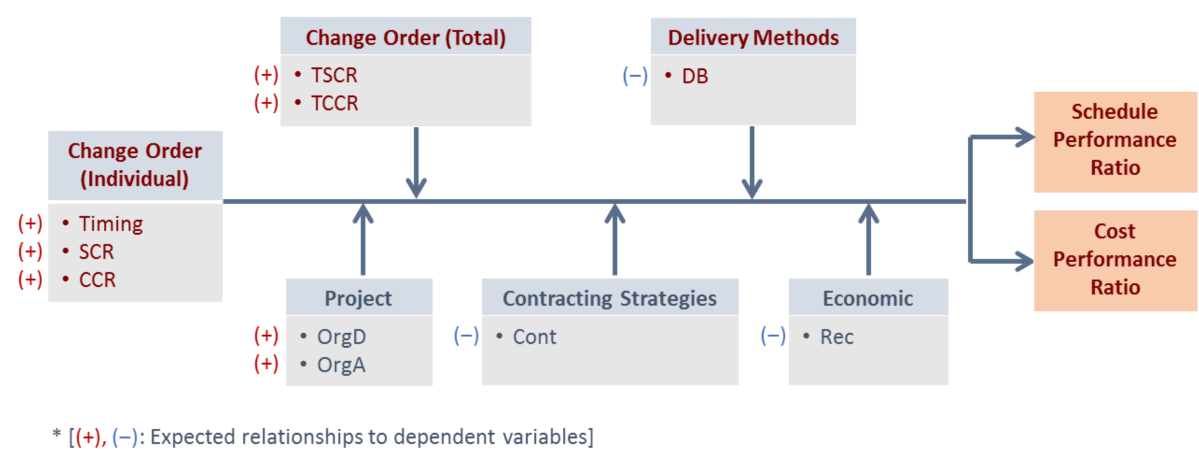


Figure 4.6. Hypothetical Model for Schedule and Cost Performance under Project Delivery Methods

4.4. Analysis Results and Discussions

From the hypothetical model developed based on the proposed Eq. (1) and (2) in Chapter 1, a multiple linear regression analysis was conducted. The required assumption check, analysis results, and corresponding implications of the findings were discussed in this section.

4.4.1. Overview of Analysis Results

To investigate the timing impacts of change order occurrence under two different project delivery methods, DB and DBB, this study analyzed the dataset of 13,710 change orders that were from 610 3R projects completed between 2002 and 2011 in Florida. Prior to arrive at the final models, the study conducted the diagnostics of assumptions required in the regression analysis. The validity of a regression model is determined based on rigid assumptions about the normality, homoscedasticity, and homogeneity of variances. The validation of these assumptions is essential for a reliable interpretation of causal relationships among the variables in the regression model (Jafarzadeh et al. 2013). With respect to the normality of residuals and heteroscedasticity, the residuals from the initial multiple linear regression analysis were abnormally distributed, thereby involving the heteroscedasticity existence. To circumvent this issue, outliers were excluded and a natural log-log transformation was applied to the OrgD and OrgA variables. In addition, as a means to detect the possible multicollinearity existence, this study diagnosed the value inflation factor (VIF) values of variables in individual model. A VIF value of 10 or more, in general, is considered as an indicator of a high correlation between/among factors (Belsley et al. 2005). The VIF diagnostic results indicated that all the calculated values did not exceed 4.

Through the assumption check, this study finalized the analysis and obtained the results, as summarized in Table 4.3. During the analysis, statistically insignificant variables were excluded by applying a stepwise regression method with backward elimination procedure. The adjusted R-squared values of the estimated performance models varied from 0.56 to 73.17 percent. Looking at the adjusted R-squared values of the final models (S-4 and C-4) for project schedule and cost performance, the variables therein explained 45.15 and 73.17 percent of the variation in the two dependent variables, SPR and CPR, respectively. One noteworthy aspect in the models are variability of change order related information. The literature indicates that the project characteristics (OrgD and OrgA) are considered as one of the most significantly influential factors on project schedule and cost performance. However, the adjusted *R*-squared values of the models with only the project characteristics variables implied that their explanation power was not high, in general. Rather, change order related factors, especially TSCR and TCCR, accounted for the more significant variability in the dependent variables.

Table 4.3. Schedule and Cost Performance Models

	Schedule Performance Model (Dependent: Schedule Performance Ratio)				Cost Performance Model (Dependent: Cost Performance Ratio)			
	S-1	S-2	S-3	S-4	C-1	C-2	C-3	C-4
Constant	0.2980***	0.4880***	0.3780***	0.3560***	-0.1450***	-0.0076	-0.0054	-0.0089
	(14.75)	(21.31)	(21.54)	(18.84)	(-22.37)	(-0.99)	(-1.07)	(-1.64)
Log (Original Contract Days)	-0.0157***	-0.0402***	-0.0388***	-0.0311***	0.0349***	0.0218***	0.0054***	0.0056***
	(-5.49)	(-12.95)	(-16.24)	(-12.61)	(31.40)	(18.62)	(8.01)	(8.19)
Log (Original Contract Amounts)	0.0160***	0.0166***	0.0158***	0.0155***			-0.0021***	-0.0021***
	(6.25)	(6.57)	(8.17)	(8.14)			(-3.65)	(-3.64)
Design-Build		-0.0660***	-0.0376***	-0.0391***			-0.00580**	-0.0058**
		(-5.22)	(-3.87)	(-4.09)			(-2.07)	(-2.07)
Alternative Contracting Strategies		-0.0296***	-0.0279***	-0.0247***		-0.0574***	0.0079***	0.0079***
		(-4.25)	(-5.19)	(-4.69)		(-21.50)	(5.11)	(5.08)
Economic Recession		-0.0845***	-0.0198***	-0.0142***		-0.0402***	-0.0216***	-0.0217***
		(-16.60)	(-4.95)	(-3.60)		(-19.47)	(-18.61)	(-18.62)
Total Schedule Change Order Ratio			1.025***	0.999***			0.0542***	0.0541***
			(78.52)	(83.32)			(13.55)	(13.54)
Total Cost Change Order Ratio			-0.0744**				0.9310***	0.9310***
			(-2.48)				(125.34)	(125.35)
Schedule Change Order Ratio (Individual)				0.6290***				
				(15.11)				
Cost Change Order Ratio (Individual)				-0.5560***				
				(-4.81)				
Change Order Occurrence Timing				-0.0595***				0.0041*
				(-7.57)				(1.78)
N	9990				12608			
Adj. R^2	0.0056	0.0386	0.4370	0.4515	0.0725	0.1396	0.7317	0.7317
F	29.07	81.14	1108.5	914.7	986.3	683.1	4912.5	4299.6

*** $p<0.01$, ** $p<0.05$, * $p<0.1$
(t statistics in parentheses)

4.4.2. Implications of Performance Models

By conducting rigorous statistical analyses on the dataset consisted of 13,710 change orders in 610 3R roadway projects, the study examined the timing impacts of change order occurrence under DB and DBB project delivery methods. As a result, this study captured several key findings, which can provide significant quantitative insights into the timing impacts of change order occurrence and the effectiveness of DB.

Project schedule and cost can be influenced by numerous factors, including project internal to external conditions. Of those, project size and duration are considered as key factors to project schedule and cost changes. Specifically, it is commonly preceived that the larger and longer the project is, the more schedule delays and cost overruns the project may experience. However, the performance impacts of the project characteristics in this study revealed somewhat different aspects. As summarized in Table 4.3, OrgD showed negative relationships with SPR, whereas OrgA had positive associations. Meanwhile, the countertrend was seen in the impacts of OrgD and OrgA on CPR. These contradictory aspects could be explained that if the project has large project budget amounts, there would follow intentional management efforts to save the costs. Conversely, managerial efforts to reduce project duration would be taken for the project with long duration. Either cost savings or duration reductions may require additional days or costs, respectively. This sort of trade-offs between schedule and cost might be a root cause of the counter effects between project size and duration on project performance.

Since the application of alternative project delivery method and contracting strategies can play a pivotal role in improving project performance, this study also examined their effectiveness. Their primary purpose is to accelerate project completion, thereby having less schedule delays than the traditional approaches. The analysis results in this study supported that they were effective in restraining schedule growths as intended. Particularly, based on the results from the model S-4, DB had less schedule delays by 3.91 percent than DBB and the use of alternative contracting strategies alleviated schedule growths by 2.47 percent than the traditional contracting strategy. DB was also helpful in constraining cost overruns, as shown in the model C-4 in Table 4.3. It showed less schedule increases of 0.58 percent than DBB. However, in the same model, it was seen that alternative contracting strategies had more cost growths than the traditional method. This would be attributed to the probable trade-offs between schedule and cost, meaning that there were more cost overruns at the expense of duration reductions.

This study has the 10-year research period between 2002 and 2011. In the late-point of the research period, there was the tremendous economic shock that had an enormous effect across the globe and nearly all industries. Rec, an indicator variable for examining the impact of the economic recession in 2008, implied that the economic crisis had effects of depression in schedule and cost increases. As stated earlier, any organizations as economic units, including the contractor and the owner, may redouble their managerial efforts to overcome challenges under the economic crisis. In particular, the results from the models S-4 and C-4 showed that 1.42 and 2.17 percent of schedule and cost reductions were implemented since 2008, respectively.

The main theme of this chapter is the timing impacts of change order occurrence on project performance. In addition, this study included other change order factors since change orders are one of root causes of schedule delays and cost overruns. The results revealed the interesting nature of change orders. Understandably, schedule and cost were significantly and positively influenced by schedule and cost change order related factors, respectively. It is noteworthy that TCCR had a statistically significant impact on schedule performance in the model S-3. However, it did not hold the statistical significance after the inclusion of SCR in the model S-4. Conversely, TSCR was strongly tied with both project schedule and cost. The models S-4 and C-4 implied that the increase of 1 percent point in TSCR can lead to 1.00 and 0.05 percent growths of project schedule and cost, respectively. With respect to the impacts of TCCR, the model C-4 indicated that 1 percent point increase in TCCR may increase of 0.93 percent in project cost.

The factors related to individual change order, SCR, CCR, and Timing, were generally associated with project schedule. Particularly, SCR and CCR were only influential on project schedule and their impacts were opposite to each other. While SCR had a positive relationship with project schedule, CCR was negatively associated with schedule increases. Negative impacts of CCR would be explained that some of cost related change orders might be employed to directly shorten project duration or might act as an indirect stimulator for accelerating project completion. With respect to the timing impacts of change order occurrence, although Timing showed a positive relationship with cost performance in the model C-4, its high *p*-value (0.0979) and identical adjusted *R*-squared values (0.7317) of the model C-3 and C-4 indicated that the impact of Timing is negligible in the estimation of cost performance. As for the most significant finding, the timing impacts of change order occurrence in this study were against the common perception and the results of the past studies. Akin to the common belief, the previous studies that have focused on the timing effects of change orders on labor productivity represented that later occurrence of change orders led to a more adverse impact on project duration. However, the results in this study revealed that change order occurrence in the later construction phase caused less schedule growths, which later change order occurrence by 10 percent of total project duration would have less schedule delays by 0.6 percent. The possible explanation for these discrepant aspects would be found from the change order practice in roadway construction projects. In practice, a significant need for the modification of project design and work scopes is likely to arise in the initial stage of the project. For instance, if required, the owner may initiate significant changes early to meet their certain special requirements or improve the project quality. In another case, unforeseen geological or social conditions detected at the beginning of construction may compel the alteration of the original design and work scopes. However, in the late project phase, the owner would not be willing to make critical changes unless they are inevitable because design and work scopes are already defined and any change may cause a substantial impact on project performance.

4.5. Summary and Conclusions

The DB project delivery method has been widely applied in the AEC industry mainly due to its decisive advantages in cutting the project duration and improving communication among stakeholders. STAs have also adopted this alternative method to fulfill the objects of fast-tracking project delivery and minimizing the inconvenience of the traveling public over the past two decades. Yet, its effectiveness on project performance still needs more investigation. Specifically, limited information is available about the impacts of change order magnitude, frequency, occurrence timing on project schedule and cost of the project under a DB setting. To fill these gaps, the study examined and compared change order aspects and project performance between DB and traditional DBB. Quantitative models for project schedule and cost were then developed by conducting a multiple linear regression analysis on the dataset of 13,710 change orders from 610 3R projects completed between 2002 and 2011 in Florida.

The study identified the following noteworthy findings through a series of analyses conducted herein. 3R DB projects experienced less frequent change orders and lower schedule and cost overruns than DBB projects. This reaffirms the findings of the most previous studies that DB was more effective in restraining change orders and the consequent unfavorable impacts of change orders on project schedule and cost. However, there was no significant difference in days and amounts added by a change order between DB and DBB projects. This implies that project delivery methods had no influence on the magnitude of a change order. Nevertheless, change order magnitudes clearly led to the adverse impacts on schedule and time performance of the project. Finally, the timing of change order occurrence mainly influenced on project schedule, while the timing impacts of change order on project cost were negligible. Particularly, the project schedule performance model presented that later occurrence of a change order caused less impacts on the growth of the total project duration.

To the best of the author’s knowledge, the study took a first step in empirically examining the timing impacts of change order occurrence under a DB setting. The findings and quantitative models developed in the study can consequently advance decision-makers’ quantitative insights toward the effectiveness of the DB delivery method and the likely timing impacts of change order occurrence.

5. PERFORMANCE IMPACTS OF ALTERNATIVE CONTRACTING STRATEGIES

This chapter addressed the second research objective, which aimed at the development of performance models that includes the simultaneity in project schedule and cost under alternative contracting strategies. By applying the three-stage least squares to the research sample of 1,053 3R projects, project schedule and cost performance models were obtained. The results affirmed the existence of the simultaneity in schedule and cost and provided quantitative insights toward the performance impacts of alternative contracting strategies and other noteworthy factors' relationships with project performance.

5.1. Alternative Contracting Strategies and Simultaneity in Schedule and Cost

Due to pressing needs for the acceleration of project completion, the use of alternative contracting strategies such as A+B, no excuse bonus, and incentive/disincentive have increased in roadway construction projects. Subsequently, there have been countless past studies on alternative contracting strategies. However, they have mainly focused on A+B and incentive/disincentive while other alternative contracting approaches such as no excuse bonus and lump sum have been understudied. Furthermore, research results about the performance impacts of alternative contracting strategies have been incongruent. Therefore, further research on the effectiveness of alternative contracting strategies is essential, especially considering the emerging needs for the substantial rehabilitation of the significantly aged and damaged roadway facilities.

Another fundamental question in this study is whether project schedule and cost are cross-correlated. Since both schedule and cost can be influenced by same or similar risk factors, they are highly likely to be interdependent (Bhargava et al. 2010; Bordat et al. 2004; Chan and Kumaraswamy 1997; Chang 2002; Choi and Kwak 2012; Flyvbjerg et al. 2003; Flyvbjerg et al. 2004; Jahren and Ashe 1990; Williams 2005; Zheng and Ng 2005). However, most of past studies have considered schedule and cost separately when conducting analysis, and only limited numbers of studies have addressed their simultaneity (Anastasopoulos et al. 2010; Bhargava et al. 2010; Lin 2005). The latter proved the existence of the simultaneity in schedule and cost. They also indicated that such simultaneity should be taken into account for the sake of the accuracy and efficiency of performance estimation.

In particular, there is no satisfactory performance models that take account of the simultaneity in schedule and cost. To tackle this gap, this study developed models that can quantify the impacts of alternative contracting strategies with consideration of the simultaneity in schedule and cost.

5.2. Performance Comparison by Alternative Contracting Strategies

Alternative contracting strategies have gained in popularity largely due to their believed advantages, such as shortening project durations or reducing project cost variances. However, their effectiveness has not been sufficiently investigated to date. To fill this knowledge gap, this study sought to compare the performance impacts of alternative contracting strategies and develop numerical models that quantify their possible impacts on project schedule and cost. To this end, the study compared their schedule and cost performance by employing statistical comparative analysis technique.

Figure 5.1 and 5.2 represent box-plots of schedule and cost performance among the five different contracting strategies: namely, conventional, A+B, no excuse bonus, I/D, and lump sum. The box-plots of schedule performance indicated that no excuse bonus and I/D had less schedule delays than the other three contracting strategies. Those of cost performance implied that A+B had more cost overruns, whereas there was no identifiable difference among the other four contracting strategies.

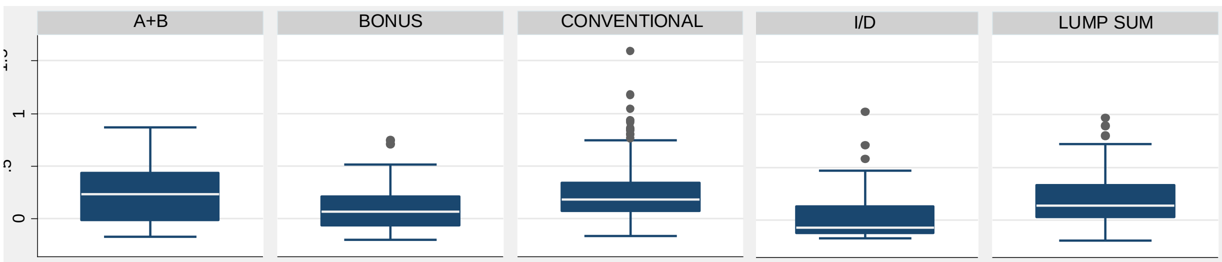


Figure 5.1. Box-Plots of Schedule Performance versus Contracting Strategies

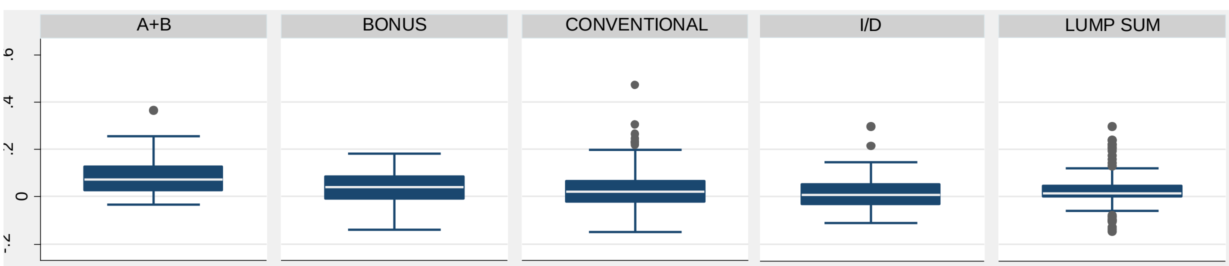


Figure 5.2. Box-Plots of Cost Performance versus Contracting Strategies

As a means to statistically compare the performance impacts of the five different contracting strategies, the one-way analysis of variance (ANOVA) test was firstly considered. However, the normality assumption that is essential for that test did not hold in both the schedule and cost performance ratio variables because their distributions are highly right-skewed, as depicted in figure 5.3. Although the study then examined whether variable transformations can circumvent the normality violence, no normal bell-shaped distribution was observed. Thus, it was concluded that parametric analysis could not be applied in this case.

Alternatively, this study conducted the Kruskal-Wallis test, which is a commonly used non-parametric analysis in the case that the normality assumption for a parametric comparative analysis cannot be met. To represent a post hoc pairwise comparison of the performance impact among the contracting strategies, the Dunn test followed. Table 5.1 and 5.2 illustrate the results from the Kruskal-Wallis rank test and Dunn test performed on schedule performance ratios. The chi-squared value of the Kruskal-Wallis rank test indicated that there was a statistically significant difference among the contracting strategy groups: chi-squared 53.532 with p-value 0.000. With respect to the pairwise comparison between contracting strategies, as shown in table 5.2, it was seen that A+B and conventional approaches had the highest severity of schedule delays, while there was no statistical difference between them, which means their schedule delay aspects were similar. Lump sum then followed. On the other hand, no excuse bonus and I/D were identified to be resistant to schedule growths than the other strategies. With respect to their statistical difference, it was found that I/D was slightly better than no excuse bonus in restraining schedule growths. In one word, their severity aspects in schedule delays could be expressed in the order of "A+B = conventional > lump sum > no excuse bonus > I/D." Only for the sake of project schedule, I/D and no excuse bonus would be favorable.

Table 5.1. Kruskal-Wallis Rank Test Results of Schedule Performance by Contracting Strategies

Contracting Strategies	N	Rank Sum	Chi-Squared
A+B	30	10722.5	53.532 (df = 4, p = 0.000)
No Excuse Bonus	38	8673.0	
Conventional	304	105570.0	
I/D	59	10553.5	
Lump Sum	195	60732.0	

Table 5.2. Schedule Performance Comparison Results from Dunn Test

Mean Difference: (a) – (b)		(a) A+B	No Excuse Bonus	Conventional	I/D
(b)	No Excuse Bonus	2.925*** (0.002)	-	-	-
	Conventional	0.293 (0.385)	-3.825*** (0.000)	-	-
	I/D	4.403*** (0.000)	1.312* (0.095)	6.545*** (0.000)	-
	Lump Sum	1.296* (0.098)	-2.595*** (0.005)	2.159** (0.015)	-4.934*** (0.000)

*** p<0.01, ** p<0.05, * p<0.1
(*p*-values in parentheses.)

The study also compared cost performance of the five contracting strategies using the same methods, as depicted in table 5.3 and 5.4. The chi-squared value of the corresponding Kruskal-Wallis rank test also revealed that cost performance among the contracting strategies was statistically different. In detail, as represented in table 5.4, A+B was identified as the worst contracting strategy on aspects of cost overruns. Contrary to the results of schedule performance comparison, no excuse bonus had more severe cost growths than conventional, I/D, and lump sum approaches. However, there was no statistically significant difference among those three contracting strategies. Therefore, the cost growth severity of the five contracting strategies can be portrayed in the order of "A+B > no excuse bonus > conventional = I/D = lump sum."

Table 5.3. Kruskal-Wallis Rank Test Results of Cost Performance by Contracting Strategies

Contracting Strategies	N	Rank Sum	Chi-Squared
A+B	30	12814.5	
No Excuse Bonus	38	13267.5	15.552
Conventional	304	93661.0	(df = 4, p = 0.004)
I/D	59	16693.0	
Lump Sum	195	59815.0	

Table 5.4. Cost Performance Comparison Results from Dunn Test

Mean Difference: (a) – (b)		(a) A+B	No Excuse Bonus	Conventional	I/D
(b)	No Excuse Bonus	1.766** (0.039)	-	-	-
	Conventional	3.440*** (0.000)	1.319* (0.094)	-	-
	I/D	3.556*** (0.000)	1.760** (0.039)	0.978 (0.164)	-
	Lump Sum	3.395*** (0.000)	1.322* (0.093)	0.082 (0.468)	-0.886 (0.188)

*** p<0.01, ** p<0.05, * p<0.1
(*p*-values in parentheses.)

Synthesizing the comparison results of the schedule and cost performance among the five contracting strategies, the overall results revealed some contrary results to the common expectations about the effectiveness of contracting strategies. Intriguingly, A+B was turned out to be the most unfavorable method both in project schedule and cost, whereas I/D showed the promising aspects in schedule and cost variances. No excuse bonus was also relatively effective in constraining schedule growths as intended, while showing the high possibility of cost overruns. Whilst there was no statistical difference in cost growths among conventional, I/D, and lump sum methods, the conventional method had the severest schedule delays and lump sum approach followed by. Therefore, the results implied that our perceptions need to be readjusted for a better selection of contracting strategies pertinent to project purposes.

5.3. Modeling Performance Impacts of Alternative Contracting Strategies

On the basis of the results of the previous comparative analysis, the study found significant differences in project performance among the contracting strategies. In addition, from the comprehensive literature review, candidate variables influencing project performance were also identified. Based on the above, the study developed numerical models that quantify the possible performance under alternative contracting strategies.

5.3.1. General Model Framework and Analysis Methods

Many prior studies and common perception indicate that project schedule and cost are intercorrelated. Therefore, special consideration was given to the simultaneity of schedule and cost in this chapter in model development. The study assumed that model functions are linear with fixed coefficients and additive residuals. This assumption would be perhaps unrealistic considering complex nature of construction projects. However, it simplifies the estimation of variable's coefficients and helps users easily understand and apply the findings. Based on this, this study initially set up the following equation system;

$$Scheudle\ Performance = \alpha_s + \beta_s \cdot X_s + \gamma_s \cdot TSCR + \theta_s \cdot TCCR + \tau_s \cdot I + \varepsilon_s \tag{3}$$

$$Cost\ Performace = \alpha_c + \beta_c \cdot X_c + \gamma_c \cdot TSCR + \theta_c \cdot TCCR + \tau_c \cdot I + \varepsilon_c \tag{4}$$

where, X_c and X_s = vectors of confounding variables affecting project schedule and cost performance, respectively; TSCR and TCCR = the ratio of total change order amounts and days over original contract amounts and days, respectively; I = indicator variable for contracting strategies; and εs = error terms.

Although the above two equations do not include direct interactions, they will have correlated error terms since cost overruns and schedule delays may be attributed to the same or similar project risks, also meaning that the same risks or changes may influence both cost overruns and schedule delays of the project. Efficient parameter estimates of this equation system can be accomplished by considering the synchronical correlation of error terms. Considering this aspect, as suitable means for the aforementioned research purpose, the study chose the following three multiple linear regression analysis based techniques that enable to take into account the simultaneity of schedule and cost performance using three-stage least squares.

5.3.2. Variables Employed in Models

This study was primarily conducted using a large quantity of real-world construction data comprised of 3,007 projects completed in Florida between 2002 and 2011. Although the data include various factors that can influence on project performance, not all aspects of the project are available. Therefore, based on the data availability along with the identification of probable variables from the literature, the following variables were selected and included in models:

Table 5.5. List of Variables Used in the Analysis

Variables		Abbreviation	Unit	Measurements
Performance (Dependent)	Schedule Performance Ratio	SPR	%	(Actual days – original contract days) / original contract days
	Cost Performance Ratio	CPR	%	(Actual amounts – original contract amounts) / original contract amounts
Project	Amount per Day	ApD	\$mil.	Original contract amounts / original contract days
	Duration – Long	DurL	-	1 if duration is the 3rd quartile (long 25%), 0 otherwise
	Duration - Medium	DurM	-	1 if duration is between 1st quartile and 3rd quartiles (medium 50%), 0 otherwise
DOT's Estimate	DOT Estimate to Original Contract Amounts	EOCA	%	DOT's initial estimate / original contract amounts
Contingency	Contingency Difference to DOT Estimate	CDE	%	(Contingency amounts – maximum contingency amounts in policy) / DOT's initial estimate

Table 5.5. List of Variables Used in the Analysis (continued)

Variables		Abbreviation	Unit	Measurements
Contracting Strategies	A+B	ContAB	-	1 if contracting strategy is A+B, 0 otherwise
	No Excuse Bonus	ContBN	-	1 if contracting strategy is no excuse bonus, 0 otherwise
	Incentive/ Disincentive	ContID	-	1 if contracting strategy is incentive/disincentive, 0 otherwise
	Lump Sum	ContLS	-	1 if contracting strategy is lump sum, 0 otherwise
Letting	Amount Percent to Total Annual Letting Amounts	PercALA	%	Original contract amounts / total annual letting amounts
	Concurrent Monthly Letting Amounts	ConcMLA	$bil.	Total letting amounts in the same month
Bidding	Bidding to Original Amounts	BOA	%	Winning bidding amounts / original contract amounts
	Number of Bidding	NB	#	Total number of biddings tendered to the project
Contractor	Major Contractor	Maj	-	1 if the awarded contractor is ranked in top 30, 0 otherwise
Economic Environment	Economic Recession	Rec	-	1 if letting year is 2008 or later, 0 otherwise
Change Order	Total Schedule Change Order Ratio	TSCR	%	Total schedule change order amounts / original contract amounts
	Total Cost Change Order Ratio	TCCR	%	Total cost change order amounts / original contract days
	Change Order Frequency	Freq	#	Total number of change orders

5.3.3. Hypothetical Model

As aforementioned, the primary purposes of this chapter are twofold: 1) quantifying the performance impacts of alternative contracting strategies and 2) taking into account the simultaneity of schedule and cost performance. On the basis of these research objectives and identified variables, the study developed the hypothetical model, as illustrated in figure 5.2.

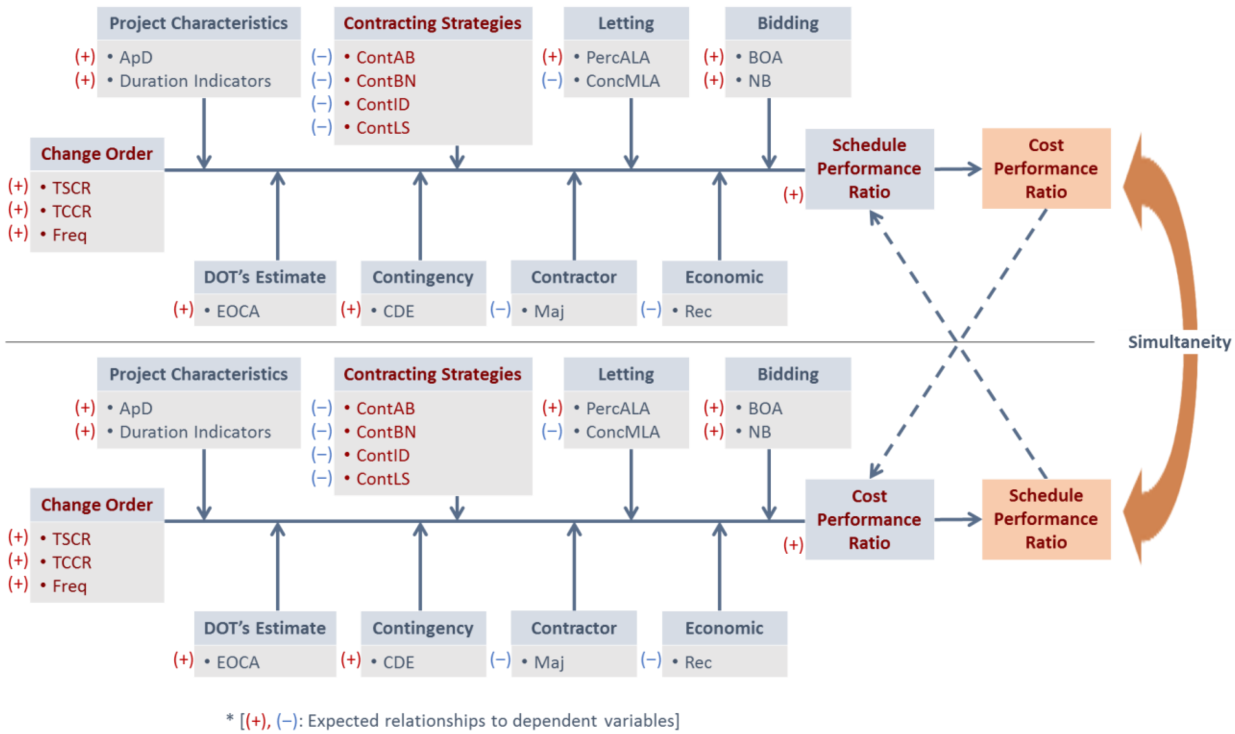


Figure 5.3. Hypothetical Model for Schedule and Cost Performance under Contracting Strategies

The primary focus of this chapter is the effectiveness of alternative contracting strategies with consideration of the simultaneity in schedule and cost. The hypothetical model in figure 5.3 illustrates the conceptual interdependency between schedule and cost performance. For the impacts of alternative contracting strategies, most of them have been applied with the intention to accelerate the project completion and/or reduce project cost. In this sense, the study initially assumed that A+B, no excuse bonus, and I/D would have less schedule delays and cost overruns than the conventional approaches. Given its natures, lump sum projects generally have relatively simple work scopes and low project complexity. Therefore, there would be also a lower probability of schedule and cost growths than the conventional approach. With respect to change order impacts, the study expected that the magnitude and frequency of change orders, which are

TSCR, TCCR, and Freq would have positive relationships with schedule and cost performance of the project.

The study also included various project internal and external factors into the model, which may affect project performance. In the literature, project size and duration are considered as significantly influential variables on project performance. It is commonly reported that the larger and longer the project is, the more schedule delays and cost overruns. Therefore, the study hypothesized that they had the same positive relationships with the dependent variables. DOT's estimate and contingency would be implicit parameters indicating the FDOT's risk anticipation toward project risks. If they forecasted high uncertainties in the project, they might estimate more cost amounts and contingency to cope with possible unexpected changes during the project implementation.

Contractors' bidding behavior may be also influenced by annual or monthly letting allotments. For instance, when the project accounts for significant amounts in annual letting allotments, the following competition among contractors may become keen. This might spur contractors' abnormally low tenders and consequently lead to schedule delays and cost overruns. On the other hand, if there are huge amounts of concurrent lettings in the same month, the bidding would be less competitive and bidding amounts would be reasonable. In the same context, high competition, which can be measured by the number of biddings, would have positive relationships with schedule and cost increases. Similar to the DOT's estimate, awarded bidders' bidding amounts may serve as a parameter that represents contractors' anticipation toward project uncertainties. The study presumed that higher bidding amounts would be positively associated with schedule and cost growths.

Even for the same project, project performance can vary depending on the expertise and capabilities of the contractor. Major contractors are usually believed to have better project implementation abilities due to their accumulated work experiences, available resources, and organizational competence (DeHoog 1990). To take this aspect into account, an indicator variable for major contractors was also included, expecting to be negatively associated with project schedule and cost growths. Finally, the research period in this study is over the 10-year span between 2002 and 2011. During that time span, there was the significant economic recession since 2008. Since external economic environments may have influence on project performance, the study used an indicator variable for the economic recession. It is anticipated that because contractors would maintain highly intensive management efforts to survive during the economic recession, project performance would be better than under the ordinary economic settings.

5.3.4. Research Methods

One of the major concerns in this chapter is the simultaneity in project schedule and cost. The schedule performance equation (3) and the cost performance equation (4) served as the simultaneous equations of this chapter. Although the study assumed the linearity between dependent and independent variables, separate estimation of coefficients for the two simultaneous equations by equation-by-equation ordinary least squares would have some major limitations. Schedule and cost performance are endogenously determined under the interrelated structural system. However, the coefficients estimated by ordinary least squares (OLS) will not efficiently reflect these simultaneous relationships. As a consequence, the coefficients will be biased and inconsistent (Bhargava et al. 2010). As statistical analysis techniques to take into account the simultaneity and overcome the limitations of the traditional OLS approach, three-stage least squares (3SLS), two-stage least squares (2SLS), and seemingly unrelated regression estimations (SURE) are widely used across various research domains. However, it is known that estimation results of SURE are efficient but not identified and the 2SLS estimation results are identified but not efficient (Lin 2005). Therefore, to yield unbiased and efficient estimates, the study employed 3SLS and compared its results with those of OLS.

5.4. Analysis Results and Discussions

On the basis of the hypothetical model, statistical analyses were conducted. Prior to performing the intended 3SLS analysis, the study examined the endogeneity of the schedule and cost performance variables, as presented in table 5.6. The 3SLS analysis was conducted and significant coefficients were estimated, as shown in table 5.6. Surprisingly, signs of some coefficients in the models indicated contradictory implications against common perceptions. The detailed explanations were addressed in the following section.

5.4.1. Existence of Endogeneity

The study assumed the probability of simultaneity between schedule delays and cost overruns in the project. Given this assumption, it must be tested whether the variables of schedule and cost performance ratios are endogenous, which means there exists the simultaneity between them. As a means to test endogeneity, Durbin-Wu-Hausman chi-square test was done. If *p*-values of the test are not smaller than an intended statistical significance level, the study cannot reject the null hypothesis that schedule delays and cost overruns are exogenous. As assumed, the test results provided the significant evidences that the endogeneity presence of schedule delays in cost overruns equation and vice versa, as indicated in table 5.6. This implies that OLS can result in biased and inefficient estimation of the simultaneous equations. To this end, the 3SLS analysis was employed to circumvent the limitations of OLS. The study used schedule performance ratio and cost performance ratio as instrument variables for the cost and schedule performance models, respectively, to unbiasedly and efficiently estimate the parameters.

Table 5.6. Durbin-Wu-Hausman Test for Endogeneity Check

Null Hypothesis	Chi-Square	*p*-Value
Schedule delays are exogenous	19.64	0.000
Cost overruns are exogenous	19.75	0.000

5.4.2. Analysis Results from Simultaneous Equations

Table 5.7 provides the estimation results from 3SLS and OLS analysis drawing on schedule and cost performance models. For the sake of the parsimony in model estimation, the study excluded statistically insignificant variables by conforming a stepwise regression technique with backward elimination procedure. The system weighted R-squared values that indicate the goodness of fit of the simultaneous equation models showed that 56.8 and 52.9 percent of the data variation was explained by the included independent variables in the schedule and cost performance models, respectively. Therefore, it can be concluded that the variables in the models may be the major factors affecting project performance, whereas there still may be additional factors beyond the scope of this study to make the model more comprehensive. With respect to model comparison between 3SLS and OLS, there was no significant difference between two methods in their system weighted R-squared values. Nevertheless, based on the Durbin-Wu-Hausman test results, it should be noted that OLS had limitations in unbiased and effective estimations. In addition, as a means to compare the performance of the two methods, the study examined the root mean square error (RMSE). The RMSE was estimated using the following equation:

$$\text{Root Mean Square Error} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}$$

The RMSE values of 3SLS in both the schedule and cost models were slightly smaller than those of OLS (0.1622 and 0.0540 in 3SLS versus 0.1636 and 0.0542 in OLS, respectively). Therefore, it could be concluded that the simultaneous equation models (3SLS) were relatively better than the single equation models (OLS).

The results from both 3SLS and OLS indicated that there exist the positive relationships between project schedule and cost performance. In particular, the two instrument variables were found to be statistically significant: that is, cost performance ratio in the schedule performance model at a 90 percent significant level, and schedule performance ratio in the cost performance model at a 99 percent significant level. However, cost performance ratio in OLS was not significant in the schedule performance model. This would affirm that OLS cannot efficiently estimate the latent simultaneity between the two dependent variables.

Table 5.7. Analysis Results of Performance Models

Variable	Schedule Performance 3SLS	Schedule Performance OLS	Cost Performance 3SLS	Cost Performance OLS
Constant	0.1571***	0.1555***	-0.0166*	-0.0127
	(8.88)	(8.69)	(-1.67)	(-1.25)
Schedule Performance Ratio			0.0649***	0.0304***
			(4.29)	(2.98)
Cost Performance Ratio	0.2472*	0.1164		
	(1.81)	(1.24)		
Amount per Day	4.0215***	4.0181***	-0.7272**	-0.5369*
(in millions of U.S. dollars)	(5.22)	(5.17)	(-2.55)	(-1.92)
Duration - Long	-0.0732***	-0.0716***	0.0375***	0.0336***
(1 if duration is long 25%, 0 otherwise)	(-3.83)	(-3.72)	(3.98)	(3.51)
Duration - Medium			0.0237***	0.0236***
(1 if duration is mid 50%, 0 otherwise)			(3.32)	(3.20)
DOT Estimate to Original Amount Ratio			0.0333***	0.0315***
			(3.34)	(3.04)
Contingency Difference to DOT			0.8814*	0.8073*
Estimation Ratio			(1.93)	(1.70)
Contracting – A+B			0.0295***	0.0285***
(1 if A+B, 0 otherwise)			(2.77)	(2.62)
Contracting – No Excuse Bonus	-0.1664***	-0.1597***		
(1 if no excuse bonus, 0 otherwise)	(-5.73)	(-5.30)		
Contracting - I/D	-0.1527***	-0.1489***		
(1 if incentive/disincentive, 0 otherwise)	(-6.82)	(-6.41)		
Contracting – Lump Sum			0.0181***	0.0187***
(1 if lump sum, 0 otherwise)			(3.48)	(3.48)
Amount Percent to Annual Lettings	-6.6313***	-6.6703***	1.7237***	1.2690**
	(-4.16)	(-4.15)	(2.92)	(2.21)
Concurrent Monthly Letting Amount	-0.1831***	-0.1866***	-0.0467*	-0.0507*
(in billions of U.S. dollars)	(-2.65)	(-2.68)	(-1.73)	(-1.85)
Bidding to Original Amount Ratio	-0.7020***	-0.6668***		
	(-5.76)	(-5.34)		
Major Contractor	-0.0460***	-0.0447***	0.0109**	0.0095*
(1 if contractor is top 30, 0 otherwise)	(-2.93)	(-2.83)	(2.06)	(1.80)
Economic Recession			-0.0340***	-0.0333***
(1 if letting year is after 2008, 0 otherwise)			(-5.44)	(-5.15)
Total Schedule Change Order Ratio	1.1276***	1.1649***		
	(18.45)	(19.90)		
Total Cost Change Order Ratio			0.9413***	0.985***
			(19.26)	(20.83)
Number of Change Order	0.0044***	0.0044***	-0.0005*	-0.0002
	(6.11)	(6.12)	(-1.86)	(-0.98)
N	594	594	594	594
RMSE	0.1622	0.1636	0.0540	0.0542
System Weighted R^2	0.5684	0.5700	0.5285	0.5377

*** p<0.01, ** p<0.05, * p<0.1
(t statistics in parentheses)

5.4.3. Impacts of Contracting Strategies and Project Attributes

This study then examined the performance impacts of project inherent characteristics by using the two parameters of project size and duration. Intriguingly, the project size variable and duration indicators had opposite effects on schedule and cost. In the schedule performance model, amount per day, which was original contract amounts divided by original contract days, had the positive estimate sign to the project schedule. Of the project duration indicators, only the projects with the 25 percent longest duration were found to be statistically significant. The negative sign of the variable estimate indicated that those projects experienced less schedule delays. Conversely, the project size and duration related factors revealed opposite aspects in the cost performance model. The project duration indicator variables showed gradually positive impacts on project cost. That is, there was a tendency that the longer project duration was, the more cost overruns would occur. However, projects with more amounts experienced less cost growths. These conflicting results would indicate that there may exist interactive effects, or trade-offs, of project characteristics on project schedule and cost variances.

Other notable factors were the FDOT's estimate and contingency-related variables. They can serve as indicators measuring the risk anticipation level of the owner toward the specific project. It was seen that they had positive relationships with project cost growths, meaning that the owner appropriately anticipated the uncertainties of the project to the extent. However, those variables had no effect on project schedule. This might suggest the needs for additional consideration of schedule contingency in the planning stage for project amounts and contingency, to cope with the possible schedule variances.

With respect to the effectiveness of alternative contracting strategies, which is one of the major concerns in this chapter, it is noteworthy that A+B and lump sum approaches had no significant impacts on project schedule, while having significantly positive effects on project cost growths. On the other hand, no excuse bonus and I/D had no significant effects on project cost, whilst negatively affecting project schedule. This implies that 1) A+B did not satisfy its intended purposes for either the acceleration of project delivery or cost savings, 2) no excuse bonus and I/D were effective in restraining schedule delays but had no cost reduction effects, and 3) despite its relatively simple work scopes, lump sum projects experienced more cost overruns.

5.4.4. Effects of Project Internal and External Factors

The study also included letting related variables in order to investigate the impacts of bidding competition and contractors' project risk anticipation. Given the nature of open procurement processes offered by the public agency, the letting schedule and information must be announced at least 90 days before the bidding date. Therefore, it is likely that contractors would be influenced by the annual or monthly letting schedule. If the project accounted for a large part of the total annual letting budget, there would be the high degree of competition and bidding amounts would be subsequently low. In this case, awarded contractors might exceed the original contract amounts and/or days. On the other hand, in the case that there were more opportunities to win projects, contractors' competition would be alleviated and place appropriate bids, having the lower probability of schedule delays and/or cost overruns. The coefficient signs of concurrent monthly letting amount supported these assumptions. It was seen that the more letting amounts in the same letting month, the less project schedule and cost increase. However, the project's proportion to total annual letting amounts had a positive relationship with project cost but a negative impact on project schedule. This could be attributed to the fact that this sort of huge-scaled projects had substantial impacts on the traveling public and adjunct communities and business. Therefore, shortening project duration would be prioritized at the expense of more cost investments. Awarded contractors' bidding amounts would be a parameter to analogize their risk anticipation. If the contractor forecasted higher uncertainties in the given project, bidding amounts would be larger than original contract amounts, having more schedule delays and/or cost overruns. However, the variable of bidding to original amount ratio did not have an impact on project cost. Rather, it had a negative relationship with project schedule. This might be due to that contractors made bidding decisions based on other factors, not the project's own risks.

The contractor's expertise and available resources may also directly differentiate project performance. It is commonly perceived that major contractors may manage the project more efficiently, thereby having less project variances. This perception was supported from the estimation results in the schedule performance model. However, major contractors experienced more cost overruns. This would be that major contractors usually construct larger projects that duration reduction would be more important. In addition to the constructor variable, external economic environments may influence project performance. To that end, this study employed the economic indicator variable representing the economic recession in 2008. The corresponding estimation results indicated that the degree of cost overruns slackened after the recession, whilst having no impact on project schedule.

Change orders are considered as a main culprit of project schedule and cost increases. They can cause schedule delays and cost overruns separately or simultaneously However, the results revealed that total cost change order ratio, which is the ratio of total cost changes caused by change orders to original contract amounts, was not associated with project schedule, while having a positive impact on project cost growths. On the other hand, total schedule change order ratio showed an opposite aspects. While not having an impact on project cost, it was positively related to only project schedule changes. Strikingly, the frequency of change order occurrence, the number of change order variable, had a contradictory impact on project cost performance. As expected, it had the positive sign to project schedule yet showed the negative sign to project cost. To investigate the causes of these conflicting results, the study examined the distribution of change order reasons. It was found that approximately 70 percent of change orders accounted for schedule extension, whereas cost related change orders were only 25 percent with the less fluctuation of cost variances. Therefore, after the effect isolation by other explanatory variables, the net impact of the frequency of change orders variables would be negative to project cost.

5.5. Summary and Conclusions

The results from the comparative analysis and simultaneous equation models in this chapter partially lent credence to the previous studies' results that alternative contracting strategies were effective. However, their detailed effectiveness revealed some conflicting aspects. Particularly, A+B seems to be the worst contracting methods due to its poor performance in both schedule and cost. No excuse bonus and I/D provisions were effective in restraining the possible schedule delays as their intention for the project delivery acceleration. Intriguingly, although lump sum projects usually had relatively simple work scopes and, consequently, less possibility of performance variances, they experienced more cost overruns. Another focus of this chapter was the simultaneity in schedule and cost. Based on the results from the Durbin-Wu-Hausman test and the 3SLS estimation, the existence of the simultaneity was significantly evidenced. To this end, it could be concluded that performance quantification frameworks should take into account the simultaneous relationships between project schedule and cost. This chapter also examined the performance impacts of various project inherent, related, and external variables. While some factors reaffirmed the previous studies' findings and common perception, the other variables opposite impacts on schedule and cost. This indicated that those factors may cause the tradeoff impacts on schedule and cost.

6. INTEGRATED CONTINGENCY ADJUSTMENT FRAMEWORK

On the basis of the research results on the effectiveness of alternative contracting strategies and the impacts of the factors in the previous chapter, the study developed a contingency adjustment framework. The proposed framework based on the path model is unique and significant because it can take into account not only the performance impacts of contracting strategies but also sequential effects of project factors in accordance with their project phases. Through the analysis, the study produced a summary table for the recommended contingency adjustment rates corresponding to given project conditions.

6.1. Need for Contingency Adjustment

Given the uncertain nature of construction, estimating and managing contingency are challenging and inherently involve a lack of accuracy. Particularly, current contingency practice usually apply the traditional fixed rate approach (Bakhshi and Touran 2014). Even worse, some agencies do not weigh the intrinsic natures of the project in their contingency allocation. A telling example that represents the failure in accurate contingency estimation is seen in projects analyzed in this study, as illustrated in Figure 3.10. In this sense, numerous prior studies have discussed methods for more accurate contingency estimating (Baccarini 2006; Bakhshi and Touran 2009; Bakhshi and Touran 2014; Chan et al. 2009; Chen and Hartman 2000; Choi et al. 2004; Paek et al. 1993; Sachs and Tiong 2009; Smith and Bohn 1999; Touran 2003; Touran 2006; Touran and Lopez 2006). Although their innovative approaches, such as probabilistic and modern mathematical methods, proved their intended performance, they usually require substantial amounts of cost and time to implement (Bakhshi and Touran 2014). Therefore, more practical contingency estimating methods need to be devised to better benefit practitioners in the roadway construction industry. In addition, the literature implies that no effort has been made to investigate sequential influences of project factors based on factor's construction phase in contingency estimation.

On the basis of the identification of issues in current contingency practice and research, the study devised a comprehensive and intuitive framework to better estimate contingency adjustment over the fixed contingency rate in the owner's policy.

6.2. Model Development for Contingency Adjustment

Construction activities, in general, can be classified by their sequential stages from planning, through bidding and procurement, to construction and completion. Each activity can serve as either a causal or affected factor to the other depending on its position in sequential processes of construction. Furthermore, their impacts may also be either direct or indirect: in other words, some factor may serve as a mediator between two different factors. The study assumed that precedent construction factors may directly and indirectly influence subsequent factors in the later construction stages. Through these pathwise relationships based on construction procedural stages, the accurate contingency amounts can be estimated.

An analytical means to reflect pathwise causal relationships is path analysis. Path analysis is a member of structural equation modeling (SEM) and can be consisted of two or more causal-effect regression models (Garson 2013). It has a distinctive advantage in visualizing complex causal and/or interrelated relationships of factors through a path diagram and providing direct and indirect impacts of factors (Garson 2013; Hair et al. 2006; Kim et al. 2009; Yuan et al.

2018). Based on the objective of this chapter and the principles of path analysis, this study established the hypothetical path model that can accurately quantify the contingency adjustment rate, as depicted in figure 6.1. This study assumed that the available information in the current construction phase directly influenced factors in the subsequent construction stage, eventually, directly and/or indirectly affecting the level of contingency adjustment rate that are essential to cope with project cost variances.

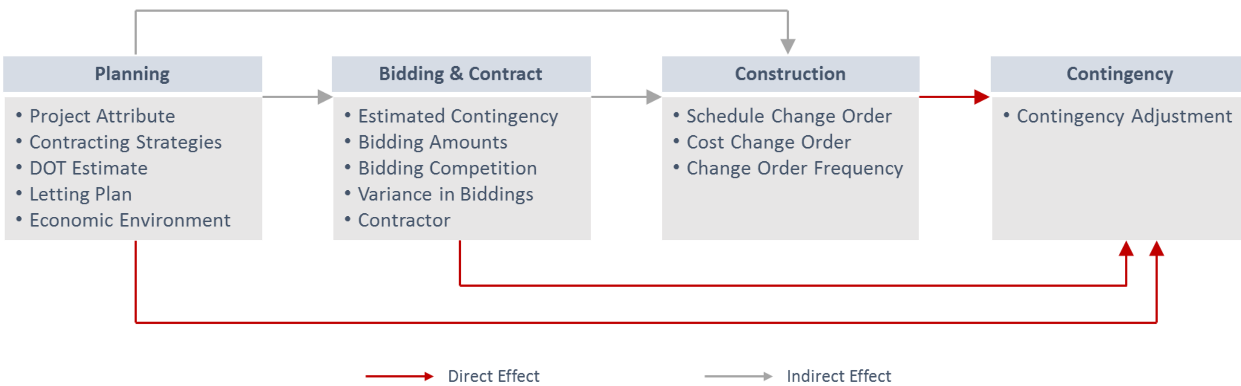


Figure 6.1. Hypothetical Path Model for Contingency Adjustment Rate

6.3. Analysis Results and Discussions

On the basis of the developed hypothetical path model, the study conducted the corresponding path analysis. By employing the stepwise backward technique, the study carefully examined the statistical significances of variables and excluded insignificant ones step wisely. The final path model results were provided in tables 6.1, 6.2, and 6.3 and figure 6.2.

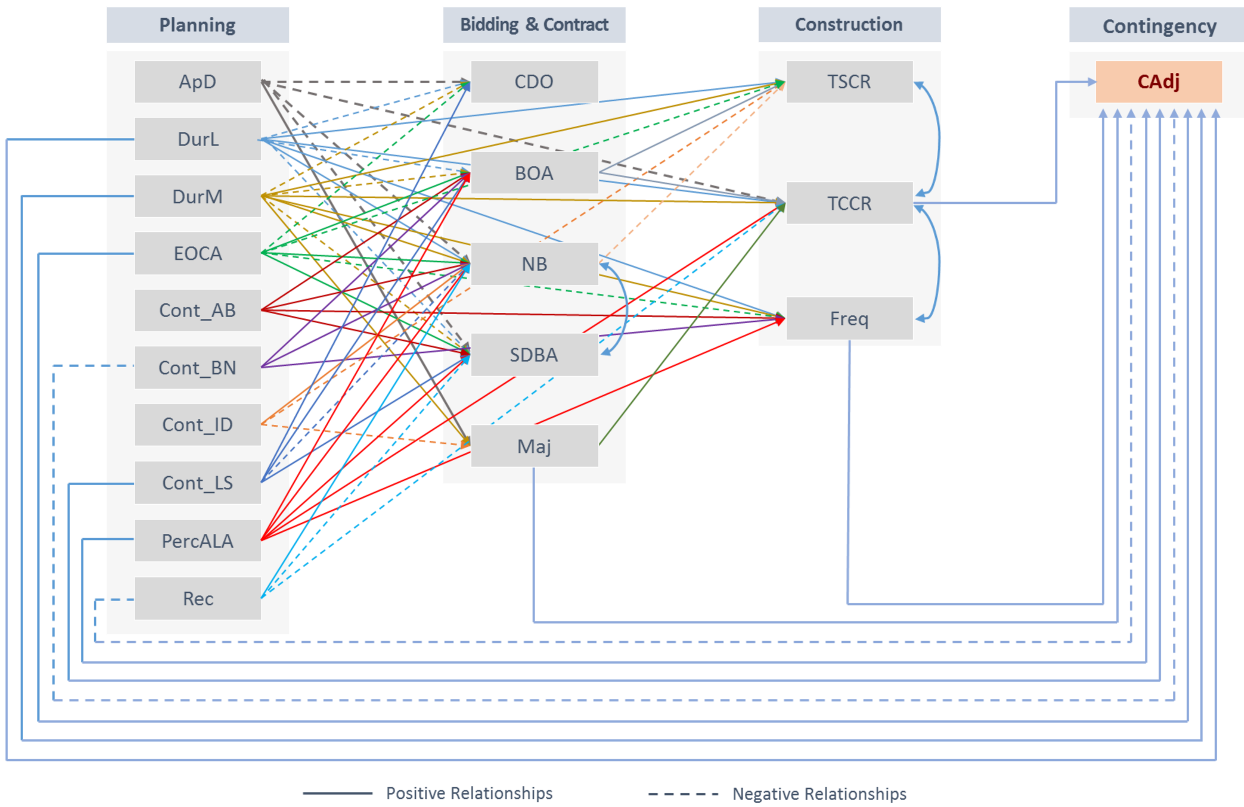


Figure 6.2. Path Model for Contingency Adjustment Rate

6.3.1. Model Fit of Path Model

Prior to investigating the effects of the variables included in the model, the study examined the goodness of fit of the proposed path model. It is recommended to consider multiple model fit indices when analyzing a path model (Marsh et al. 1996). The study examined the indices of chi-square/degree of freedom, root mean square error of approximation (RMSEA), root mean square residual (RMR), comparative fit index (CFI), and Tucke-Lewis (TLI). Table 6.1 provides model fit indices, recommended benchmarks, and measured values. Since all index values fell into the ranges of recommended benchmarks, it can be concluded that the model has a good fit in general (Browne and Cudeck 1989; Schreiber et al. 2006; Wang et al. 1996). This also indicates that all relationships of the variables in the model were significant.

Table 6.1. Model Fit Indices and Recommended Benchmarks

Fit Index	Recommended Benchmarks	Value
Chi-square / Degree of Freedom	$1 \leq Chi^2 / DF \leq 5$; Lower value is better	2.248
Root Mean Square Error of Approximation (RMSEA)	Good if RMSEA ≤ 0.05; Acceptable if RMSEA ≤ 0.1	0.045
Root Mean Squared Residual (RMR)	Perfect fit if 0; Smaller value is better	0.026
Comparative Fit Index (CFI)	Acceptable if CFI ≥ 0.9	0.967
Tucker-Lewis Index (TLI)	Acceptable if TLI ≥ 0.9	0.932

The study applied the stepwise backward approach to obtain an optimized path model. Therefore, insignificant factors were excluded through this procedure. Figure 6.3 displays the entire pathways of the variables in the final path model. The solid lines indicate the positive relationships, while the dash lines reveal the negative relationships. Table 6.2 provides the standardized and unstandardized coefficients in individual path equations. In general, all variables' relationships were statistically significant at more than a 90 percent significant level. Moreover, the R-squared values of individual path equations ranged 8.46 to 49.78 and the overall path model's R-squared was 94.27.

Table 6.2. Result Summary of Individual Path Equation

Variable		Bidding & Contract					Construction			Contingency
		CDO	BOA	NB	SDBA	Maj	TSCR	TCCR	Freq	CAdj
Planning	ApD	-0.1091***		-44.4786***	-2.3442***	8.9011***		-0.5946**		
		-(0.1369)		-(0.2831)	-(0.2622)	(0.2535)		-(0.1436)		
	DurL	-0.0078***	-0.0447***	0.5144***	-0.0968***		0.0274***	0.0241***	16.5398***	0.0671***
		-(0.3620)	-(0.3798)	(0.1179)	-(0.3899)		(0.1560)	(0.2097)	(0.5191)	(0.3610)
	DurM	-0.0094***	-0.0294***		-0.0909***	0.1142***	0.0183***	0.0156**	3.9176***	0.0334***
		-(0.4584)	-(0.2707)		-(0.3967)	(0.1269)	(0.1128)	(0.1472)	(0.1332)	(0.1947)
	EstOrgA	0.0184***	0.0322***	2.3314***	0.1246***		-0.0246**		-3.3757**	0.0258**
		(0.4316)	(0.1420)	(0.2771)	(0.2604)		-(0.0726)		-(0.0550)	(0.0720)
	Cont_AB		0.1703***	0.7871**	0.0387*				7.8617***	
			(0.6681)	(0.0833)	(0.0719)				(0.1140)	
	Cont_BN		0.0220***	0.6175***					4.4088***	-0.0229**
			(0.1003)	(0.0761)					(0.0744)	-(0.0661)
	Cont_ID			1.2406		-0.1268**	-0.0239**			
				(0.1879)		-(0.0860)	-(0.0901)			
	Cont_LS	0.0024***	0.0080**	-0.3232**	0.0248***					0.0246***
		(0.1105)	(0.0689)	-(0.0755)	(0.1018)					(0.1349)
	PerALA		0.5313**	34.7178**	1.9846**			0.8953*	898.2503***	1.4193***
			(0.0655)	(0.1156)	(0.1161)			(0.1131)	(0.4095)	(0.1109)
	Rec			1.0767***	-0.0272***			-0.0122***		-0.0372***
				(0.2585)	-(0.1148)			-(0.1111)		-(0.2095)
Bidding & Contract	CDO									
	BOA						0.2462***	0.0964**		
							(0.1651)	(0.0987)		
	NB						-0.0032**		0.5525***	
							-(0.0802)		(0.0757)	
	SDBA									
	Maj							0.0078*		0.0129**
								(0.0661)		(0.0675)
Construction	TSCR									0.2042***
										(0.1929)
	TCCR									0.6103***
										(0.3775)
	Freq									
Contingency	CAdj									

Table 6.2. Result Summary of Individual Path Equation (continued)

Variable	Bidding & Contract					Construction			Contingency
	CDO	BOA	NB	SDBA	Maj	TSCR	TCCR	Freq	CAdj
Constant	0.0088***	0.0524***	3.6798***	0.2135***	0.5198***	0.0278**	0.0005	0.7156	-0.0750***
	(0.8652)	(0.9705)	(1.8408)	(1.8765)	(1.1635)	(0.3457)	(0.0099)	(0.0490)	-(0.8803)
Error Term	0.0001	0.0015	2.6963	0.0096	0.1827	0.0061	0.0026	82.3295	0.0043
	(0.5814)	(0.5022)	(0.6747)	(0.7414)	(0.9154)	(0.9441)	(0.9531)	(0.3863)	(0.5954)
Covariance			0.0143**				0.0010***	0.0646***	
			(0.0891)				(0.2399)	(0.1384)	
							0.1722***	(TSCR & Freq)	
							(0.2427)		
Chi-Squared	137.13	(*p*=0.000)							
R-squared (Individual)	0.4186	0.4978	0.3253	0.2586	0.0846	0.0559	0.0469	0.6137	0.4046
R-squared (Overall)	0.9427								

*** p<0.01, ** p<0.05, * p<0.1
(Standardized coefficient values in parentheses)

6.3.2. Path Analysis Results - Bidding and Contract

As factors available in the planning phase, the study included the variables of project size, duration, contracting strategies, estimate to the original contract amount, letting information, and economic recession. With respect to their relationships with the variables in the subsequent bidding and contract stage, contingency difference to original contract amounts (CDO) were negatively influenced by amount per day (ApD), project duration indicators (DurL and DurM), and estimate to original amounts (EOCA), whereas lump sum contracting (Cont_LS) had a positive impact. This indicates that the owner assigned lower contingency than their maximum contingency amounts for projects with larger amounts and longer duration. The possible reason for this tendency would be the belief that huge-scaled and long-span projects may have more rooms for absorbing performance variances. However, considering that the impacts of those variables on the contingency adjustment rate variable, this inappropriate contingency practice needs to be adjusted. It was found that alternative contracting strategies for delivery acceleration, i.e., A+B, no excuse bonus, and I/D had no significant relationships with the owner's contingency. These contracting strategies have a contractual structure that the partial risks of performance variances are transferred to the contractor. Therefore, it was likely that the owner did not take them into account when assigning consistency. Meanwhile, lump sum was positively associated with the owner's contingency differences. Along with its positive relationship with the contingency adjustment rate, it seems that the owner appropriately anticipated the possible cost overrun risks of lump sum approach. However, it should be noted that CDO was not related to any further factors. This clearly evidences that the contingency practice did not adequately reflect the project risks.

The next factor considered in the bidding and contract stage was winning bidder's amounts to original contract amounts (BOA), which represents the contractor's risk anticipation level. The coefficients' signs indicates that the contractor's bidding amounts had a proportional relationship with the cost-related information, i.e., estimate to original contract amounts (EstOrgA) and amount percent to annual letting amounts (PerALA). Conversely, project duration was disproportionally associated with BOA. This may portray that the contractor may have a tacit scheme of time-cost tradeoff. For instance, the contractor is likely to increase bidding amounts along with project size, while they may attempt to obtain profit by shortening the duration. With respect to contracting strategies' effects, all but I/D had significant positive relationships with BOA. As aforementioned, because alternative contracting strategies structurally transfer the project risks to the contractor, some risk premium would be added.

It is highly likely that information in the planning phase stimulates the degree of bidding competition. In this sense, number of bidding (NB) was also included and examined. For the negative coefficient sign of ApM, project size increase may act as an entry barrier for small-mid sized contractors, thereby having less competition. However, in the case that the project accounted for a large amount of total annual letting, PerALA, the project would attract contractors' attention or there would be a limited number of other lettings. Therefore, the competition would be ignited. EstOrgA is the variance between the owner's estimate and contracted, or negotiated, amounts. This may mean the project had more variance in project risk anticipation among bidding participants. Subsequently, more contractors would place a bid. Concerning alternative contracting strategies, A+B, no excuse bonus, and I/D gathered more biddings, whereas lump sum had less. The former may have an opportunity to gain additional profit due to their compensational nature, yet lump sum is unit price so that may have no additional chance for profit. This would cause the difference in the level of bidding competition. With respect to the impact of external economic environments, it is clearly seen that the economic recession (Rec) increased the competition.

The study expected that the standard deviation of bidding amounts (SDBA) variable would serve as a parameter representing the degree of risk perception disparity among bidders. However, the increases in project size and duration were negatively related to SDBA. This may indicate that contractors' bidding behavior was irrelative of project risks. Rather, considering the impacts of the other variables, contractors tend to make a bidding decision based on other factors beyond the scope of this study. To take an example, they might decide bidding amounts according to the surrounding situation: specifically, with an opportunistic intention based on the market circumstances and competitors' behavior. This conjecture could be supported by the impact of the Rec variable. Because the construction industry is highly subject to economic fluctuation, contractors may bid their possible lowest prices without an opportunistic intention to survive during the economic recession, consequently, having less bidding amount deviation among bidders. SDBA was surely positively correlated to NB, which means the more bidders, the more deviation in bidding amounts. It is notable that SDBA had no further relationship to the next construction phase variables. This means that the degree of contractors' bidding amount variances did not necessarily reflect their differences in project risk anticipation.

Finally, the characteristic of awarded contactors (Maj) was considered in the bidding and contract phase. ApM can act as an entry barrier so that major contractors were awarded more contacts. In projects with duration between short 25 and long 25 percent (DurM), major contractors became distinguished, while they were less successful in I/D projects. The R-squared value of this individual was only 8.46 percent. Therefore, the success or failure of major contractors in contract awarding needs more compounding variables beyond this study.

6.3.3. Path Analysis Results - Construction

Once bidding and contract procedures are done, the project will be under construction and encounter with unexpected changes: namely, change orders involving schedule and cost variances. Since construction projects are inherently uncertain, change orders are inevitable regardless of project characteristics. In this section, the study examined the impacts of the variable in the previous phase on the change order variables in the construction stage.

As a measurement of schedule related change orders in the given project, total schedule change order ratio (TSCR) was used. The two duration indicators (DurL and DurM) were directly and positively associated with TSCR. However, with respect to the owner's estimate (EstOrgaA) and awarded contractor's bidding amounts (BOA), their relational aspects to TSCR were diagonally opposite. Whereas bidding amounts had a positive relationship, owner estimate was negatively associated with TSCR. These conflicting results may represent the both parties' different standpoints toward schedule change order. From the contractor side, they would recognize monetary value of project time and, consequently, reflect the possible schedule changes in project cost estimation. However, the owner would be less subject to schedule changes because the primary responsibility would be on the contractor. As for impacts of contracting strategies, A+B, no excuse bonus, and lump sum were significant but I/D showed a negative relationship with TSCR. This reaffirms the findings of the previous chapter and sections that I/D was effective in suppressing schedule growths. It was seen that NB was negatively associated with TSCR. This would imply that bidding competition play a role in restraining schedule change order.

Subsequent to schedule change order, the study also examined total cost change order ratio (TCCR). The duration indicators (DurL and DurM) clearly showed their adverse impacts on TCCR. However, cost related variables – ApD, PerALA, and BOA – had different relationships with TCCR. Project size (ApM) was negatively associated with cost change order, while the project's proportion in total annual letting amounts (PerALA) and awarded contractor's bidding amounts (BOA) had a positive relationship. With regard to project size, huge-scaled projects would have substantial impacts on project participants, surrounding communities, and traveling public. Therefore, there would be more managerial attention from both the owner and contractor, resulting in less cost change order. Yet, the project's proportion in total annual amounts may also account for the number of available lettings, which would be also related to an awarding possibility of the contractor. Therefore, the contractor might bid abnormally low amounts and attempt to recoup the loss by occurring more cost change order. By the same token, if the contractor placed higher bidding amounts than original contract amounts, he/she might also try to meet his/her intended benefit with more cost change order.. However, the negative coefficient sign of the economic recession (Rec) may indicate that the contractor refrained from those attempts for the survival under the economic hardship. The contractor attribute indicator Maj implies that major contractors had more cost change order. This would be attributed to the fact that they usually construct huge-scaled projects with high uncertainties. From the covariance matrix, it was also found that TSCR and TCCR were positively correlated so that they would have a simultaneous relationship.

Finally, the frequency of change order (Freq) was considered in the construction stage. The results indicate that project size did not have an impact on Freq, whereas projects with long duration experienced more frequent change orders. One interesting relationship in this individual path equation was the impact of EstOrgA. The negative sign may indicate that the owner's estimate did not adequately take the possible change order occurrence into account. As for the impacts of contracting strategies, A+B and no excuse bonus experienced more frequent change orders. However, considering the other equations, it should be noted that this necessarily means they caused more schedule and cost changes. The PerALA and NB variables provided the same implications with those of TCCR. On the basis of their positive relationships with Freq, it is possible to assume that the contractor might attempt more change orders. Freq was also correlated with both TSCR and TCCR. Without a doubt, the more change orders there were, the more schedule and cost changes were accompanied.

6.3.4. Contingency Adjustment Rate

The primary objective of this chapter is to accurately quantify contingency adjustment rate based on the pathwise relationships along with the project's sequential stages. Therefore, in the proposed path model, all pathway arrows were eventually gathered in the contingency adjustment rate (CAdj) variable. In this section, the decomposed effects as well as the coefficient signs of the significant variables were discussed.

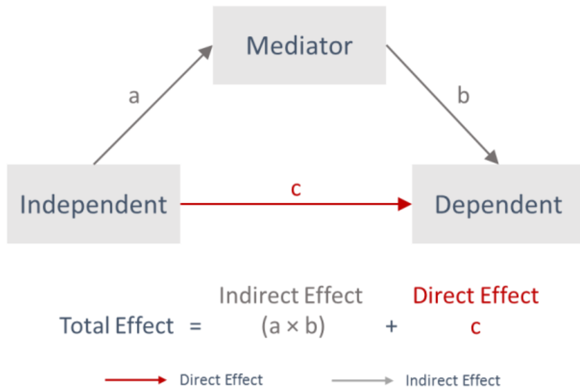


Figure 6.3. Measurement Principle of Total Effect to Dependent Variable in Path Analysis

When interpreting a causal effect in a path analysis, the path multiplication rule should be applied, which is defined that the effect value of compound path is the product of its path coefficients (Garson 2013). For instance, as illustrated in figure 6.3, if we have a simple path model with three variables of independent, mediator, and dependent, the effect of the independent variable through the mediator to the dependent is the product of the two coefficients in the pathways: that is, a × b. Even when there are more pathways, the same principal can be applied. Under the effect decomposition rule, total effect of the independent variable can be decomposed into an indirect effect and a direct effect (Alwin and Hauser 1975; Garson 2013; Schreiber et al. 2006). The aforementioned effect is the indirect effect of the independent through the mediator on the dependent. The direct of the independent variable on the dependent variable is c. By summing the both, the total effect of a × b + c can be estimated. Following the two aforementioned principals, the study excerpted a part of the path model, as depicted in Figure

6.4, and decomposed the effects of the significant variables on the contingency adjustment rate variable, as provided in table 6.3. For better understanding, the study conducted the effect composition based on the unstandardized coefficient values. The study expects that the results in table 6.3 and 6.4 will serve as a contingency adjustment matrix for the owner when allocating contingency.

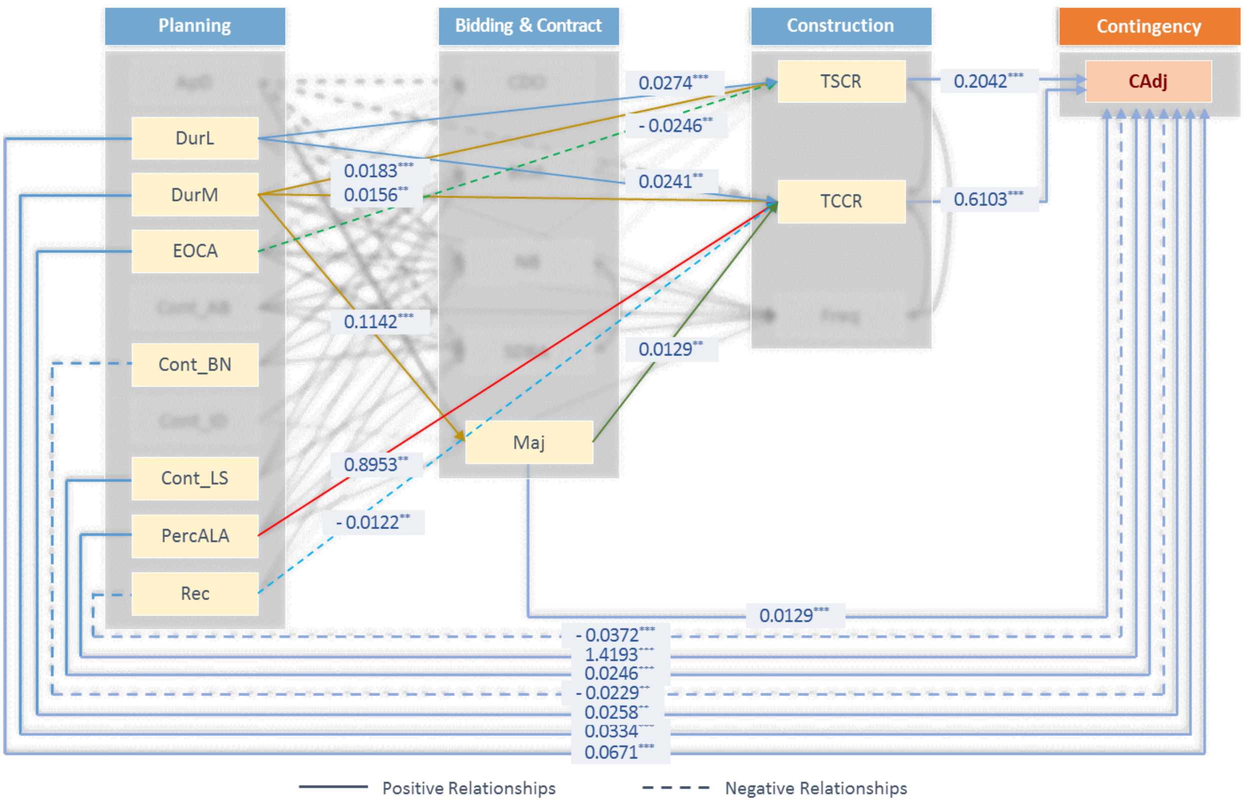


Figure 6.4. Excerpted Path Model for Effect Decomposition

Table 6.3. Contingency Adjustment Rate Matrix - Effect Decomposition of Significant Variables

Effect to Dependent Variable (CAdj)			Effect of Variables in Path to Dependent Variable		
Variable	Effect Type	Effect Value	Maj	TSCR	TCCR
DurL	Indirect	0.0203		0.0056	0.0147
	Direct	0.0671			
	Total	0.0874			
DurM	Indirect	0.0133	0.0015	0.0037	0.0095
	Direct	0.0334			
	Total	0.0467			
EOCA	Indirect	-0.0050		-0.0050	
	Direct	0.0258			
	Total	0.0208			
Cont_BN	Indirect	0.0000			
	Direct	-0.0229			
	Total	-0.0229			
Cont_LS	Indirect	0.0000			
	Direct	0.0246			
	Total	0.0246			
PerALA	Indirect	0.5464			0.5464
	Direct	1.4193			
	Total	1.9657			
Rec	Indirect	-0.0074			-0.0074
	Direct	-0.0372			
	Total	-0.0446			
Maj	Indirect	0.0048			0.0048
	Direct	0.0129			
	Total	0.0176			
TSCR	Indirect	0.0000			
	Direct	0.2042			
	Total	0.2042			
TCCR	Indirect	0.0000			
	Direct	0.6103			
	Total	0.6103			

As for the project inherent characteristics, it was found that project size (ApD) was not statistically significant. However, from the statistical significance levels and standardized coefficient values of the two project duration indicators (DurL and DurM), there was a strong evidence that projects with long duration require more contingency allocation. This is also in line with the findings that project duration also had unfavorable impacts on schedule and cost change. The total effect values present that the project ranked in the quartiles of long 25 and medium 50 percent may need additional contingency amounts equivalent to 8.74 and 4.67 percent of original contract amounts on top of the maximum contingency amounts in the policy, respectively.

The owner estimate (EOCA), which would be an indicator of the owner's risk anticipation level, coincided with the actual project cost variances, in general. However, it should be also noted that consideration on schedule change orders was not sufficiently taken, as indicated in EOCA's indirect effect value. Based on the estimated total effect, 0.02 percent of original contract amounts should be added as per 1 percent increase of the owner estimate to original contract amounts.

With regard to the effectiveness of alternative contracting strategies, it was shown that no excuse bonus (Cont_BN) provision can contribute to the reduction of contingency. That is, the owner would be able to deduct 2.29 percent of original contract amounts from the maximum contingency amounts in the policy. Meanwhile, lump sum (Cont_LS) projects may require more contingency assignments. The total effect value indicates that lump sum projects need additional 2.46 percent of original contract amounts.

The letting information also can serve as a parameter for contingency. In the case that the project accounts for a large part of the total annual letting amounts, the owner should take consideration on that information. The total effect value indicates that 1 percent increase of the project in the proportion of the total annual letting amounts would require additional contingency amounts of 1.97 percent of original contract amounts.

If the economic environments are in decline, the owner would be able to retrench contingency budgets by 4.46 percent of original contract amounts. However, the contractor is a major contractor, ranked within top 30, 1.76 percent of original contract amounts may be required.

The magnitudes of schedule and cost change order also need consideration in assigning contingency. The results indicate that 0.20 and 0.61 percent of original amounts would have to be added per 1 percent increase in the total schedule and cost change order ratios, respectively. However, contrary to the other significant variables that would be available in the bidding and contract phase, change order related information cannot be identified before the construction commencement. In this case, the owner could estimate approximate values of total schedule and cost change order ratios using the corresponding equations in table 6.2.

6.4. Summary and Conclusions

Contingency serves as an essential monetary buffer to cope with project risks and uncertainties that can cause cost growths. However, current contingency practices do not meet the purpose of contingency. Moreover, the literature implies that it lacks a comprehensive contingency estimation framework that addresses the sequential aspects of the project and the effectiveness of alternative contracting strategies. To this end, this study developed the comprehensive path model that visually represent the relationships of factors along with the project life-cycle stages from planning, through bidding and contract, to construction and completion. On the basis of this framework, the study obtained the matrix for contingency adjustment rate that can be applied as per the given conditions and information of the project. The matrix provides the following notable implications: 1) project size is not a significant factor, 2) the length of project duration should be reflected proportionally to contingency, 3) when the owner estimate exceeds original contract amounts, it could be a signal for additional contingency, 4) with no excuse bonus provision, contingency can be reduced yet increased with lump sum, 5) if the project accounts for substantial portion of the total annual letting amounts, more contingency would be required, 6) in the economic recession, reduced contingency would be available, and 7) the project constructed by a major contractor may need more contingency. It is expected that the findings and results in this chapter will help agencies and practitioners grasp comprehensive relationships among factors and assist them to more accurately estimate contingency. In addition, although the framework presented in this chapter is only limited to rehabilitation projects in the certain singe agency, it can be extended to other project work types and regions.

7. CONCLUSIONS

The current U.S. highway system is severely aged and deteriorated because most of roadways already exceeded their intended life span. In addition, the situation has been worsened by the failure to meet the drastic increase in traffic demand. As a result, the rehabilitation of existing roadways has become a major concern of the nation on aspects of social welfare and national economy. However, roadway renewal can lead to other significant concomitant issues such as traffic delay, public inconvenience, accident, and consequent economic losses due to construction work zones. As a partial solution to those issues, alternative delivery method and contracting strategies have been employed over the last three decades. However, it is still controversial as to whether such alternative approaches are effective.

To this end, the study primarily focused on the development of models that can quantify the effectiveness of alternative project delivery and contracting strategies. In particular, based on the research gaps identified through the literature review, the study has achieved the following three research objectives: (1) quantification of change order occurrence timing impacts under project delivery methods; (2) development of performance models with the simultaneity in project schedule and cost under alternative contracting strategies; and (3) establishment of a comprehensive but point-and-shoot contingency estimation framework that takes account of the effectiveness of alternative contracting strategies.

The research objectives were achieved by analyzing a total of 3,007 transportation infrastructure improvement projects completed between 2002 and 2011 in Florida. Given the current roadway construction trend shift from new construction to rehabilitation, the study mainly focused on 1,103 rehabilitation, reconstruction, and resurfacing projects. The study conducted a series of statistical analyses such as comparative analysis, multiple linear regression, three stage least squares, and path analysis in accordance with the corresponding research objectives.

For the effectiveness of project delivery methods, it was found that alternative delivery approach, DB, was more effective in restraining unfavorable cost overruns as well as schedule delays than the traditional DBB method. The multiple linear regression analysis results indicated that the magnitude of change order caused more schedule and cost growths, in general. The timing impacts of change order occurrence on project performance were the main focus of interest in this analysis. Contrary to the previous studies, the later occurrence of change order had less impacts on project schedule. Meanwhile, although change order occurrence timing showed a positive relationship with cost performance, its impact was statistically negligible.

In the chapter for the second research objective, the study examined the performance impacts of four alternative contracting strategies: A+B, no excuse bonus, incentive/disincentive, and lump sum. The results from the Kruskal-Wallis tests indicated that A+B had the highest level of schedule delays and cost overruns. No excuse bonus was effective in constraining schedule delays while having relatively high cost overruns. Incentive/disincentive appears to satisfy its purpose of duration reduction while showing no significant cost performance difference from the conventional contracting strategies. Intriguingly, lump sum showed conflicting aspects to expectations that it would have less schedule and cost growths due to its relatively simple work scope and low project risks, The consequent three-stage least square analysis provided the similar results and reaffirmed the previous studies' results that there exist the simultaneity in schedule and cost.

From the above findings, the study developed a contingency adjustment framework using the path model and obtained the summary table for contingency adjustment recommendation along with given project conditions. The noteworthy findings are as the following. Contrast to the literature, project size was not a significant factor while project duration had significant impacts on the required contingency adjustment. Also, the owner estimate was positively associated with contingency adjustment. It was found that the no excuse bonus provision and the economic recession would alleviate contingency burden. Finally, projects performed by major contractors required more contingency allocation.

The results and findings from this study would have important contributions to the existing body of knowledge since the study presented quantitative information about the effectiveness of alternative project delivery method and contracting strategies with the integration of the simultaneity in schedule and cost. Also, the contingency adjustment framework developed in this study is the first of its kind in visually and quantitatively representing sequential impacts of factors. The models also provided support for the comprehensive understanding about diverse factors that can affect project performance. In short, the implications of this study will assist decision makers and practitioners in the transportation construction industry to better anticipate the performance impacts of factors as well as alternative project delivery method and contracting strategies, improving planning and management practice through planning, bidding and contract, and construction phases.

The intentions and results of the study outline the following implications for future work. First, the research scope in this study was only 3R projects. Further research extended to other project work types, i.e., new construction, bridge, capacity added, and others, will enrich the understanding about the performance impacts of alternative project delivery method and contracting strategies, and also other factors. Second, the research area was limited in the state of Florida. Therefore, it would be valuable to examine the aspects of variables using nationwide or global level data. Third, the research ideas can be implemented using other analysis techniques to compare analysis results and to derive more significant findings. For instance, although this study considered ANN methods as a main research tool in the stage of research planning, multiple linear regression, three-stage least square, and path analysis were eventually selected because the data sample size was not sufficient to conduct ANNs. The inclusion of more abundant dataset obtained from multiple states or nations will enable the use of ANNs and other analysis methods, thereby drawing significant results.

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